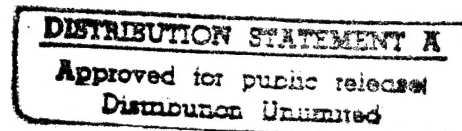


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Investigation of the Effect of Resin Material on Impact Damage to Graphite/Epoxy Composites

R. J. Palmer



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16. Abstract This report describes the results of an experimental program that establishes the feasibility and guide lines for new resins development. The objective was to identify the basic epoxy neat resin properties that will improve low velocity impact resistance and toughness to graphite/epoxy laminates and, at the same time, maintain useful structural laminate mechanical properties. Material tests from twenty-three toughened epoxy resin matrix systems are included in this investigation. The apparent desirable neat resin properties to obtain the best combination of impact and mechanical composite properties are tensile strength above 6.89×10^7 Newtons/m ² (10,000 psi); tensile modulus above 3.10×10^9 Newtons/m ² (450,000 psi), and tensile elongation between 5 and 6%. <div style="text-align: center;">5010 QUALITY INSPECTED 2</div>					
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FORWARD

This document is the final report on research into the effect of modified tough resins on the damage tolerance of graphite/epoxy laminates conducted under task 56 of contract NAS1-12675. The work was conducted from June, 1978 to Sept, 1980. Jerry G. Williams of Langley Research Center, Hampton, Virginia was the NASA technical monitor of the contract.

Mr. C.Y. Kam of the Douglas Aircraft Company was the program manager with technical activity being accomplished under the direction of Mr. R.J. Palmer. Materials and Process Engineering. Principle contributors to the Douglas activities were Mr. T. Loffenberg and G. Rodgers of Materials and Process Engineering. Thanks is expressed to all those in industry who supplied materials and data to enrich the development.

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SUMMARY

The results of an experimental program are described to evaluate the effects of "toughened" epoxy resin matrix systems (twenty-three in all) on both their ability to reduce the damage caused by low velocity impact and to retain high mechanical properties in graphite/epoxy laminates. The results of this program are intended to assist in establishing the guidelines for new resin developments.

The program was conducted in a series of five tasks as follows:

- TASK 1 Basic neat resin properties of tensile, tensile modulus of elasticity and percent elongation were measured on most of the materials. Resin systems were selected with a wide variation of tensile properties.
- TASK 2 These materials were obtained in prepreg tape form on Thornel 300 graphite and fabricated into thin isotropic fiber pattern plates, and tested for tolerance to free-fall round and blunt end impact damage.
- TASK 3 These same materials were also fabricated into plates, cut into coupon size and tested for tensile, compression, shear and flexural mechanical properties.
- TASK 4 These same materials were also fabricated into thick orthotropic plates and tested for impact damage tolerance and retained compressive strength after impact. The thick laminate plates were tested at NASA-Langley, and results will be published under a separate NASA report.
- TASK 5 The data gathered during Task 1, 2, and 3 were assessed and a discussion presented on correlation of test results.

The significant conclusion of this investigation is that modification of the epoxy resin matrix properties used in a graphite composite laminate can reduce the damage caused by low velocity impact. This can be achieved with minimal changes in room temperature mechanical properties. The apparent desirable neat resin properties to obtain the best combination of impact and mechanical composite properties are resin tensile strength above 6.89×10^7 N/m² (10,000 psi), tensile modulus above 3.10×10^9 N/m² (450,000 psi), and tensile elongation between 5 and 6%.

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1.0 INTRODUCTION

Advanced composite materials are now being used in structural applications on a routine basis in military aircraft and are being applied to commercial aviation. Graphite/epoxy is the leading material to offer lightweight, strong, rigid structure and, at the same time, offer the potential for low-cost fabrication. It is expected that the surfaces of these structural components will be subjected to foreign object impact. This impact could cause significant damage at any time during initial fabrication and assembly operations, ground handling and take off, in-flight and landing operating conditions.

Studies, such as those sponsored by NASA and the Naval Air Development Center, have been conducted to determine the impact tolerance of current in use graphite/epoxy materials. (References 1, 2 and 4). These studies have shown that low velocity, hard object impact damage causes significant reduction of retained tensile and compression strength, even when the damage levels cannot be visually observed. Thin laminates showed decreasing residual tensile strength as the impact energy was increased beyond the visual threshold through extensive fracture of the fibers in the laminate. (Reference 3.) Thick 3.2 mm (1/4 inch) composite panels showed as much as 50 % reduction in retained compression strength and strain even when no visual surface damage was in evidence. (Reference 2.) NDT techniques using ultrasonic C-scan were used to exhibit the extent of internal damage.

The reduction in retained strength of less than visual impact damaged panels places a limiting strain factor in the structural component design that reduces the potential weight savings of the composites.

The objective of this program was to establish if a "toughened" resin matrix system could improve the impact resistance of a graphite/epoxy laminate. It has been observed that low level of impact failure in both thin and thick laminates is associated with brittle resin failure, that is, resin cracking (crazing) and interlaminar failure prior to actual fiber breakage that occurs at higher impact loads. It was projected that a combination of higher resin tensile, lower modulus or higher elongation should add toughness to the resin and improve impact properties of the resultant laminates. This was the logic that directed the development of a "tough" resin system.

The "toughening" was accomplished by resin and prepreg manufacturers who varied by any means at their disposal the neat resin tensile, modulus and percent elongation properties with damage tolerance improvements as the singular objective. The materials, twenty-three in all, were supplied to Douglas as "B" stage unidirectional Thornel 300 tape. The materials were made into 8 and 48 ply panels for thin and thick laminate impact study. Thin laminate impact evaluations were made at Douglas. Thick laminate impact studies were made at NASA-Langley and are not repeated herein. In addition, unidirectional fiber orientation panels were fabricated and tested for flexural strength and modulus, short beam shear strength, tensile and compression strength and modulus at room temperature.

The data was reduced to determine any correlation between neat resin properties and the extent of impact damage to thin panels, and between neat resin properties and laminate mechanical properties.

2.0 TECHNICAL APPROACH AND TEST RESULTS

This section covers the detail of the technical approach and a summary of the test results to determine the effects of resin modification (toughened matrix) on impact resistance and mechanical properties of graphite/epoxy composites.

The program was conducted and is reported in a series of 5 tasks:

- TASK 1 - Material Selection and Neat Resin Properties
- TASK 2 - Thin Laminate Impact Properties
- TASK 3 - Laminate Mechanical Properties
- TASK 4 - Thick Laminate Impact Resistance
- TASK 5 - Correlation of Test Results

2.1 TASK 1 - MATERIAL SELECTION

A survey was first made to select the epoxy resin manufacturers and graphite prepreg material suppliers that had active in-house resin development programs aimed at formulating improved "tough" graphite/epoxy material systems. The selected organizations that were interested in working on this NASA-sponsored program were then presented a summary of the objectives, scope, and limitations of the expected work. Narmco 5208/T-300 material was selected as a baseline material with which to compare test results. It is a widely used material with a large available data base.

The basic objective was to identify and establish the credibility of the assumption that modification of resin matrix properties of tensile strength, modulus of elasticity and/or percent tensile elongation properties could have significant effect on the impact resistant properties of graphite/epoxy structure. The program has considered only one variable, namely the resin matrix system. The same Thornel 300 (3000 filament) fiber was used throughout the program and although not from the same batch was assumed to be of consistent quality. There was no limit placed on processing cycles, and there was no attempt requested to optimize material handling properties. It was expected that new laboratory-prepared resins, with tailored "toughness" properties, might be difficult to handle in preparation of test panels. There was no request for any type of temperature or liquid environmental resistant properties, and no such tests were conducted. The long process for optimization of a potential new "tough" resin matrix system to obtain the most desirable handling, processing, and environmental characteristics could follow only after it was proven that such effort could be expected to be worthwhile. Such development would not be a part of this program.

The participating organizations were asked to supply 1.36 Kg (3-pounds) quantities of each modified resin system in a unidirectional prepreg tape form between 2.54 and 30.5 cm. (1 and 12 inches) in width, 150 ± 5 grams/square meter Thornel 300 fiber areal weight which corresponds to .13 mm (.005 inch) per ply cured laminate thickness, and between 35 and 45% resin content. In addition, complete processing instructions were supplied for each material. Some materials were supplied as "no charge" samples and others were purchased.

Finally, each supplier was asked to furnish, where possible, tensile properties of the neat resin system used. Preferably, the information was requested to be in the form of a stress vs. strain curve with data reduction for tensile ultimate, tensile modulus of elasticity, and percent elongation at failure.

A total of 23 different modified resin systems were obtained and tested during work on this program. Several systems were tested for effect of high and low resin content. The list of suppliers participating in the program along with their material identification numbers are listed in Table 1. In addition, a summary of all available neat resin properties and the general approach taken to provide the resin toughening mechanism are recorded in Table 1.

All available neat resin stress/strain curves are plotted in Figure 1. All neat resin properties, including stress/strain curves, were supplied by the individual suppliers. The neat resins were cast by most suppliers to the desired thickness and cured by a slow process in an oven to the final curing temperature. Coupons were machined to dog bone specimen configuration and tested for tensile load vs. deflection to failure.

Identification of commercial products in this report is used to adequately describe the test materials. Neither the identification of these commercial products nor the results of the investigation published therein constitute official endorsement, expressed or implied, of any such product by either The Douglas Aircraft Company or NASA.

2.2 TASK 2 -THIN LAMINATE IMPACT PROPERTIES

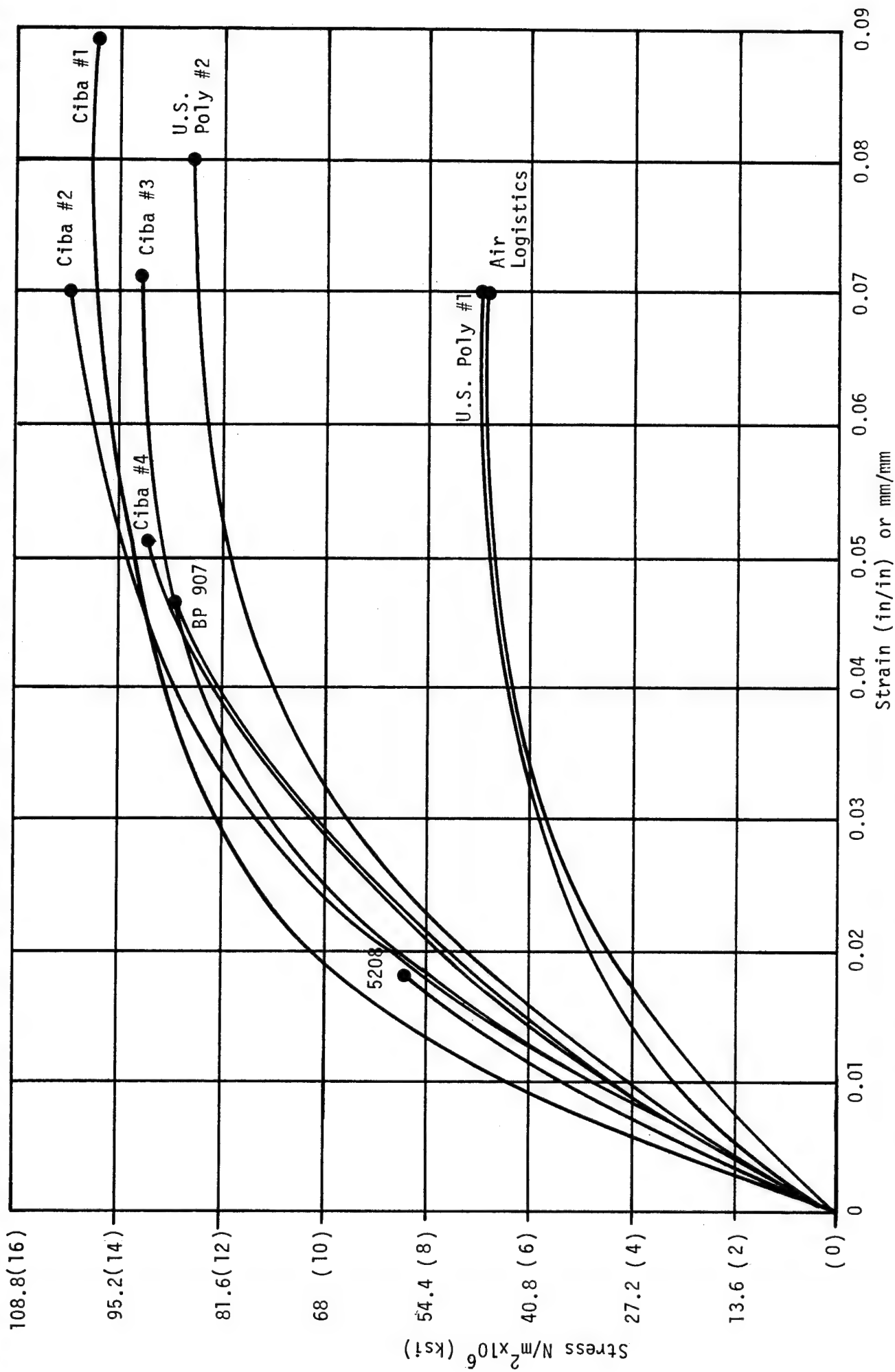
Materials were received from each of the suppliers along with quality control data of prepreg resin content and a recommended processing cycle. All plates required for the impact evaluation tests and the mechanical property tests were manufactured in a single processing cycle for each material system. All plates for thin laminate impact study were 8 ply [0,45,-45,90]_s fiber pattern and all plates for mechanical property evaluation were of 0⁰ fiber pattern. Every curing cycle was monitored as to time, temperature, and pressure to be sure that the exact specification suggested by each of the suppliers was followed. These curing cycles were not optimized for the new laboratory scale toughened resin systems, and the possibility exists that an altered curing cycle investigation could have revised the impact and or mechanical property test results obtained on the cured laminates. Observe the effect presented later in Section 2.6 of this report of the altered slow cure cycle for Narmco

TABLE 1
NEAT RESIN PROPERTIES

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	RESIN TOUGHENING MECHANISM	RESIN PROPERTIES		
				NEAT TENSILE ULTIMATE N/M ² X 10 ⁷ (PSI)	TENSILE MODULUS N/M ² X 10 ⁷ (PSI)	% ELONGATION AT FAILURE
1	Narmco	5208	MY-720 Aromatic Amine	5.72 (8,300)	399.6 (580,000)	1.5
2	Narmco	95995	Epoxy Aromatic Amine	7.44 (10,800)	373.4 (542,000)	2.4
3	Narmco	X1114	Bis-Phenol A Nonaromatic Amine + Elastomers	3.15 (4,500)	165.3 (240,000)	6.0
4	Narmco	X108/34A	Bis-Phenol A Aromatic Amine + Elastomers	-	-	-
5	Narmco	107	Bis-Phenol A Nonaromatic Amine + Elastomers	-	-	-
6	Narmco	109	Bis-Phenol A Nonaromatic Amine + Elastomers	-	-	-
7	American Cyanamid	BP-907	Bis-Phenol A Latent Aliphatic Amine Vinyl Resin	8.92 (13,000)	310.1 (450,000)	4.8
8	American Cyanamid	919	Bis-Phenol A/Epoxy Novalac Latent Aliphatic Amine + Elastomers	-	-	-
9	American Cyanamid	937	Bis-Phenol A + Specialty Latent Aromatic Plus Aliphatic Amine + Elastomers	-	-	-
10	American Cyanamid	982	Bis-Phenol A/Epoxy Novalac Latent Aromatic and Aliphatic Amines	-	-	-

TABLE 1 (Cont'd)

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	RESIN TOUGHENING MECHANISM	RESIN PROPERTIES		
				NEAT TENSILE ULTIMATE N/M ² X 10 ⁷ (PSI)	TENSILE MODULUS N/M ² X 10 ⁷ (PSI)	% ELONGATION AT FAILURE
11	Air Logistics	#1	Amine-Cured Elastomer Modified Bis-Phenol Epoxy	4.75 (6,900)	172.2 (250,000)	8.0
12	Ciba Geigy	#1	Hydantoin Aromatic Amine	9.92 (14,400)	443.7 (644,000)	8.7
13	Ciba Geigy	#1M	Hydantoin Aromatic Amine + Thermoplastic	-	-	-
14	Ciba Geigy	#2	Hydantoin Aromatic Amine	10.33 (15,000)	330.7 (480,000)	7.0
15	Ciba Geigy	#3	Hydantoin Aromatic Amine	9.43 (13,700)	333.5 (484,000)	7.0
16	Ciba Geigy	#4	Bis-Phenol A Aliphatic Amine + Thermoplastic	8.92 (13,000)	332.1 (482,000)	4.6
17	Ciba Geigy	Fiberdux 920	Bis-Phenol A Aliphatic Amine + Thermoplastic	7.51 (10,900)	312.1 (453,000)	4.1
18	Ciba Geigy	Fiberdux 914	Multifunctional Epoxy + Thermoplastic	4.96 (7,200)	399.6 (580,000)	1.4
19	Hexcel	#1	Bis-Phenol A High Function- ality Epoxy Di-Cy + Elastomer	5.30 (7,700)	220.5 (320,000)	7.0
20	Hexcel	#2	Bis-Phenol A and F Di-Cy + Elastomer	4.47 (6,500)	254.9 (370,000)	1.9
21	Fiberite	HY-E 976	High Functionality Epoxy Aromatic Amine	6.20 (9,000)	257.6 (400,000)	5.0
22	U.S. Poly- meric	#1	Bis-Phenol A + Specialty Aromatic Amine + Elastomers	4.82 (7,000)	234.3 (340,000)	19
23	U.S. Poly- meric	#2	Bis-Phenol A + Specialty	9.37 (13,600)	-	8



NOTE: Curves are averaged results as recorded by various testing agencies and are intended to show general relationships.

FIGURE 1. TOUGH RESIN STRESS-STRAIN CURVES

5208 material and the resultant across the board improvement in all mechanical properties and impact properties (at least when tested at room temperature). We do not know the difference that the modified cure cycle makes in the basic neat resin properties. This optimization was considered beyond the scope of this program.

Table 2 summarizes the supplier recommended curing cycle for each individual material.

2.2.1 Impact Tests

All panels for the thin laminate impact tests contained an eight-layer balanced 0,+45,-45,90 fiber pattern. Quality control tests for each panel included a thickness measurement, resin and void content obtained by using the hot nitric acid digestion process, and a nondestructive test (NDT) C-scan print.

Impact tests were conducted on all materials using the Garnder Impact Tester and a portion of the materials using the Rheometric Constant Speed Impact Tester.

2.2.2 Gardner Impact Test

The Gardner Impact Tester, see Figure 2, used a free fall, .9 kilograms (two-pounds) weight, in the form of a 15.9 mm (5/8 inch) diameter rod with a rounded 15.9 mm (5/8 inch) diameter impact nose or a flat blunt 15.9 mm (5/8 inch) diameter impact nose. (See Figure 3.) The rod was lifted to a measured height, in Millimeters (inches), and was released for free fall down a guide tube to impact the specimen in a single impact.

All materials were impacted on the Gardner Impact Tester with a 31.8 mm (1.25 inch) diameter simple support, a 15.9 mm (5/8 inch) diameter impact head, and 1.13 (10), 2.26 (20) and 3.39 joules (30 inch pounds) free fall energy. All materials were also impacted on the Gardner Impact Tester with a 95.3 mm (3.75 inch) diameter simple support, a 15.9 mm (5/8 inch) diameter flat impact head, and at various levels between 1.13 joules (10) and 11.3 joules (100 inch pounds) free fall impact energy. (See Figure 2.)

The evidence and extent of visible back side damage from all Gardner Impact Tests in the 0° and 90° to surface fiber orientation are recorded in Table 3. A tabulation of all impact tests is presented for all materials in Appendix I that includes visual observations of both front and back side surfaces, a C-scan record, the square inch area of damage as shown by C-scan, and a general comment on failure appearance.

Appendix II shows the damage to aluminum of equal weight and of equal thickness when impacted at the same levels.

TABLE 2
RECOMMENDED CURE CYCLES

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	CURING SPECIFICATIONS
1	Narmco	5208	Room temp. to 135°C (275°F) 1.6 to 4.4°C/min (3 to 8°F) vacuum pressure then 6.9×10^5 N/m ² (100 psi)/vent vacuum then 176°C(350°F)/ 6.9×10^5 N/M ² (100 psi) 2 hours.
2	Narmco	95995	6.9×10^5 N/M ² (100 psi) from room temperature to 176°C (350°F) and hold 2 hours.
3	Narmco	X-1114	6.9×10^5 N/M ² (100 psi) from room temperature to 121°C (250°F) and hold for 1 hour.
4	Narmco	X-108/34A	6.9×10^5 N/M ² (100 psi) from room temperature to 176°C (350°F) and hold for 1 1/2 hours.
5	Narmco	107	Room temp. to 176°C (350°F) at 2.7°C/min (5°F) under vacuum then 6.9×10^5 N/M ² (100 psi) to 176°C (350°F) for 90 minutes.
6	Narmco	109	Vacuum pressure from room temperature to 176°C (350°F) at 2.7°C/min (5°F) then 6.9×10^5 N/M ² (100 psi) and 176°C (350°F) for 90 minutes.
7	American Cyanamid	BP-907	Apply vacuum and heat to 121°C (250°F) and hold for 1 hour. Apply 6.9×10^5 N/M ² and heat to 176°C (350°F) and hold for 1 hours (100 psi).
8	American Cyanamid	919	Apply vacuum and heat to 65°C (150°F) and hold for 1 hour. Then apply 6.9×10^5 N/M ² (100 psi) and heat to 121°C (250°F) and hold for 1 hour.
9	American Cyanamid	937	Apply vacuum and heat to 121°C (250°F) and hold for 1 hour. Then apply 6.9×10^5 N/M ² (100 psi) and heat to 176°C (350°F) and hold for 1 hour.
10	American Cyanamid	982	Apply vacuum and heat to 121°C (250°F) and hold for 1 hour. Then apply 6.9×10^5 N/M ² (100 psi) and heat to 176°C (350°F) and hold for 1 hour.
11	Air Logistics	#1	6.9×10^5 N/M ² (100 psi) from room temperature to 149°C (300°F) and hold for 2 hours.
12	Ciba Geigy	#1	30 min./room temp./vacuum. Raise pressure to 2×10^5 N/M ² (30 psi) then temperature to 100°C (212°F) for 90 minutes then 176°C (350°F) for 3 hours at 5.5×10^5 N/m ² (80 psi).
13	Ciba Geigy	#1M	30 min/room temp/vacuum. Raise temp. to 100°C (212°F) under vacuum then apply 6.9×10^5 N/M ² (100 psi). Raise temperature to 176°C (350°F) and hold for 3 hours.

TABLE 2 (Cont'd)

NO.	NAME OF SUPPLIER	MATERIAL IDENTIFICATION	CURING SPECIFICATIONS
14	Ciba Geigy	#2	30 min./R.T./vacuum. Raise pressure to $6.7 \times 10^5 \text{N/M}^2$ (95 psi) then temperature to 79°C (174°F) and hold 90 minutes. Cool. Then post cure 2 hours at 300°F .
15	Ciba Geigy	#3	Raise pressure to $5.5 \times 10^5 \text{N/M}^2$ and temperature to 100°C (210°F) and hold for 90 minutes. Temp. to 176°C (350°F) and hold $5.5 \times 10^5 \text{N/M}^2$ (80 psi) for 3 hours.
16	Ciba Geigy	#4	Apply vacuum for 1 hour and then heat to 100°C (210°F) and apply $6.9 \times 10^5 \text{N/M}^2$ (100 psi) then heat to 121°C (250°F) and hold for 1 hour.
17	Ciba Geigy	Fiberdux 920	Apply vacuum and heat to 82°C (180°F), then apply $6.9 \times 10^5 \text{N/M}^2$ (100 psi) and heat to 121°C (250°F) and hold for 1 hour.
18	Ciba Geigy	Fiberdux 914	Apply vacuum pressure and heat to 121°C (250°F). Then apply $6.9 \times 10^5 \text{N/M}^2$ (100 psi), vent vacuum and heat to 176°C (350°F) and hold for 1 hour. Post cure 4 hours at 204°C (400°F).
19	Hexcel	#1	Apply $3.5 \times 10^5 \text{N/M}^2$ (50 psi) and heat to 121°C (250°F) hold for 1 hour.
20	Hexcel	#2	Apply $5.6 \times 10^5 \text{N/M}^2$ (80 psi) and heat to 176°C (350°F) hold for 1 hour.
21	Fiberite	HY-E 976	Apply vacuum and heat to 121°C (250°F) and hold for 20 min. Apply $6.9 \times 10^5 \text{N/M}^2$ (100 psi), Hold 45 minutes at 121°C (250°F) then increase temp. to 176°C (350°F) and hold for 2 hours.
22	U.S. Polymeric	#1	R.T. to 135°C (275°F) - Vacuum and hold for 30 minutes. Then apply $6.9 \times 10^5 \text{N/M}^2$ (100 psi) and 176°C (350°F) and hold for 4 hours.
23	U.S. Polymeric	#2	Apply $6.9 \times 10^5 \text{N/M}^2$ (100 psi) and heat to 149°C (300°F) hold for 2 hours.

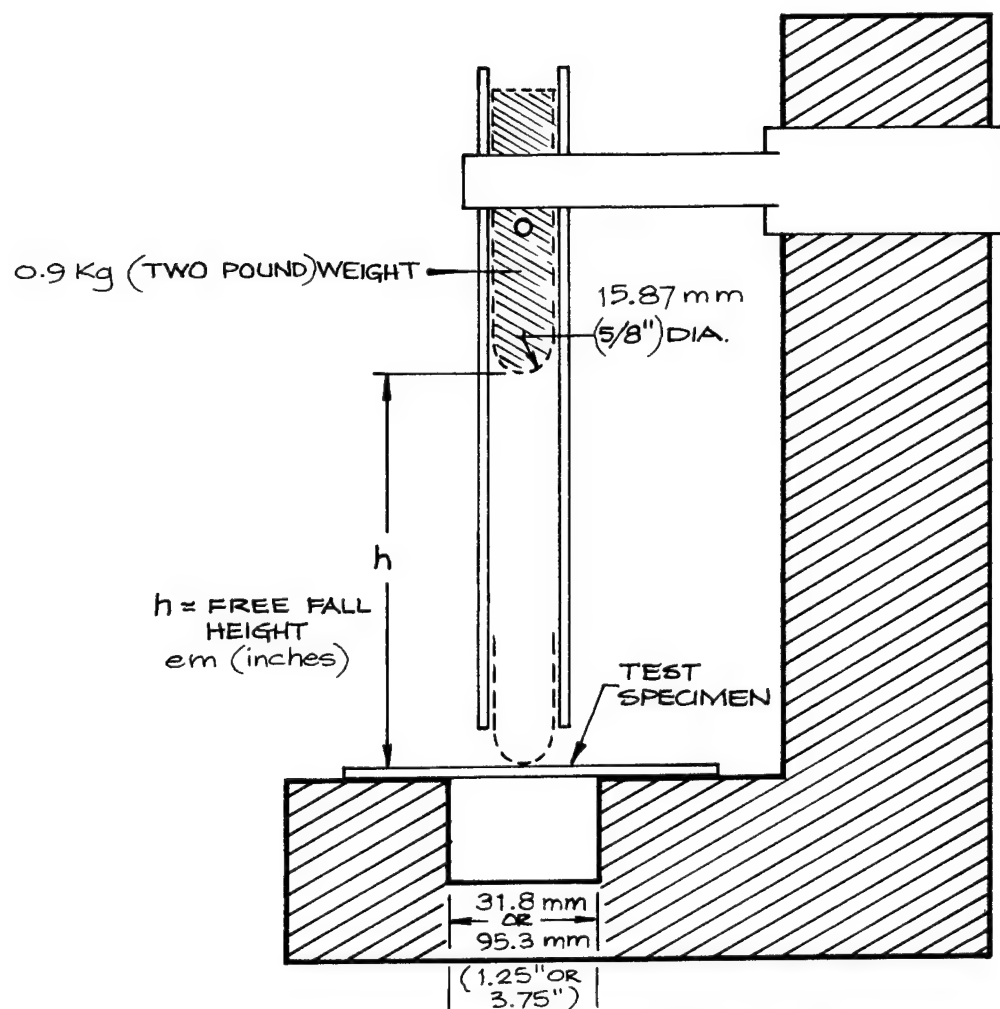


FIGURE 2. GARDNER IMPACT TESTER

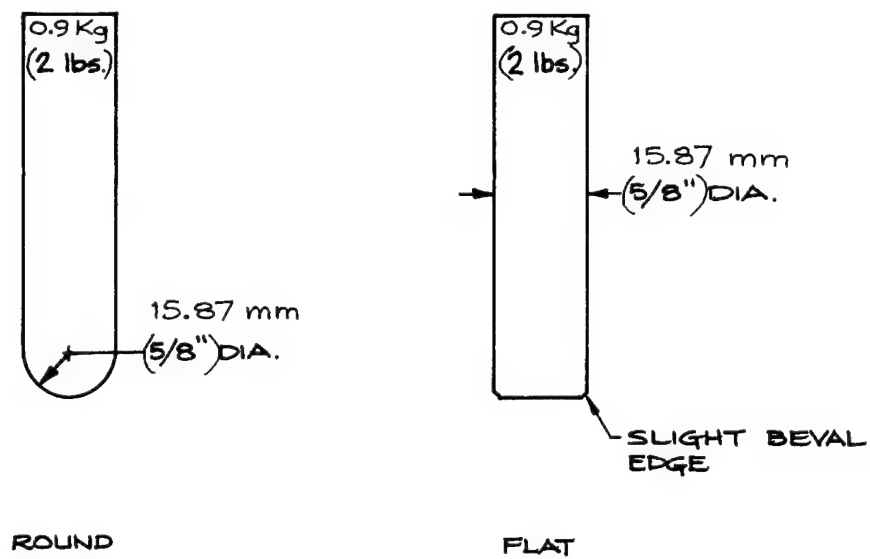


FIGURE 3. GARDNER ROUND AND FLAT IMPACT HEADS

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		FIBREDUX 920	HEXCEL #2	CIBA GEIGY #4	NARMCO X1114	NARMCO X108/34A
(1.25") 31.7 mm SUPPORT 5/8" ROUND IMPACT HEAD	RESIN CONTENT	31.7	29.9	27.5	30.0	25.4
	TOTAL THICKNESS (IN) mm	(.044) 1.12	(.042) 1.07	(.047) 1.19	(.050) 1.27	(.042) 1.07
	PLY THICKNESS (IN) mm	(.0055) .142	(.0052) .132	(.0059) .149	(.0061) .155	(.0052) .132
	(10" LB) X	(0) 0 *	(0) 0	(0) 0	(0) 0	(.1) 2.54
	1.13 Joules Y	(0) 0	(0) 0	(0) 0	(0) 0	(1.0) 25.4
(3.75") 92.2 mm SUPPORT (5/8") 15.8 mm ROUND IMPACT HEAD (5/8") 15.8 mm FLAT IMPACT HEAD	(20" LB) X	(.4) 10.16		(.1) 2.54	(.2) 5.1	(.3) 7.62
	2.26 Joules Y	(.3) 7.62		(1.2) 30.5	(.1) 2.54	(1.5) 38
	(30" LB) X	(.5) 12.7	(.1) 2.54	(.3) 7.62	(.2) 5.1	(.4) 10.16
	3.39 Joules Y	(.5) 12.7	(1.0) 2.54	(1.2) 30.5	(.3) 7.62	(1.5) 38
	(10" LB) X	(0) 0	(0) 0			
	1.13 Joules Y	(0) 0	(0) 0			
	(20" LB) X	(0) 0				
	2.26 Joules Y	(0) 0				
	(30" LB) X	(.5) 12.7	(.2) 5.08			
	3.39 Joules Y	(.3) 7.62	(1.2) 30.5			
	(40" LB) X					
	4.52 Joules Y					
	(50" LB) X					
	5.65 Joules Y					
	(60" LB) X			(0) 0	(1.2) 30.5	(0) 0
	6.78 Joules Y			(0) 0	(.2) 5.1	(0) 0
	(70" LB) X	(1.4) 35.56			(1.0) 25.4	(0) 0
	7.91 Joules Y	(.5) 12.7			(.5) 12.7	(0) 0
	(80" LB) X	(2.7) 68.6	(0) 0	(1.3) 33.02		(1.0) 25.4
	9.04 Joules Y	(.6) 15.24	(0) 0	(1.3) 33.02		(1.2) 30.5
	(90" LB) X		(1.0) 2.54	(.7) 17.8		
	10.17 Joules Y		(1.5) 38.1	(3.2)		
	(100" LB) X					
	11.3 Joules Y					
	(120" LB) X					
	13.56 Joules Y					

* NOTE: UNITS ARE (INCHES) MILLIMETERS IN THE X AND Y DIRECTION OF AREA OF DAMAGE

②

TABLE 3
VISIBLE IMPACT DAMAGE ON THIN LAMINATES 8 PLY ($\pm 45, 90$)_s

	NARMCO X108/34A	U.S. POLY #2	5208 SLOW CURE	FIBREDUX 920 LOW RESIN	CIBA GEIGY #1M	A. M. CYAN BP907 LOW RESIN	CY S
	25.4	24.6	26.4	29.2	26.5	29.6	3
7 .155	$\frac{(.042) 1.07}{(.0052) .132}$	$\frac{(.043) 1.09}{(.0051) .132}$	$\frac{(.043) 1.09}{(.0054) .137}$	$\frac{(.043) 1.09}{(.0054) .137}$	$\frac{(.043) 1.09}{(.0054) .137}$	$\frac{(.043) 1.09}{(.0054) .137}$	$\frac{(.043)}{(.0054) .137}$
	$\begin{pmatrix} (.1) 2.54 \\ (1.0) 25.4 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.2) 5.1 \\ (.1) 2.54 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.2) 5.1 \\ (.2) 5.1 \end{pmatrix}$	$\begin{pmatrix} (.2) \\ (.1) \end{pmatrix}$
54	$\begin{pmatrix} (.3) 7.62 \\ (1.5) 38 \end{pmatrix}$	$\begin{pmatrix} (.2) 5.1 \\ (1.0) 25.4 \end{pmatrix}$	$\begin{pmatrix} (.2) 5.1 \\ (1.0) 25.4 \end{pmatrix}$	$\begin{pmatrix} (.4) 10.16 \\ (.3) 7.62 \end{pmatrix}$	$\begin{pmatrix} (.2) 5.1 \\ (1.5) 38 \end{pmatrix}$	$\begin{pmatrix} (.2) 5.1 \\ (.4) 10.16 \end{pmatrix}$	$\begin{pmatrix} (.5) \\ (1.2) \end{pmatrix}$
52	$\begin{pmatrix} (.4) 10.16 \\ (1.5) 38 \end{pmatrix}$	$\begin{pmatrix} (.4) 10.2 \\ (1.2) 30.5 \end{pmatrix}$	$\begin{pmatrix} (.3) 7.62 \\ (1.2) 30.5 \end{pmatrix}$	$\begin{pmatrix} (.5) 12.7 \\ (.5) 12.7 \end{pmatrix}$	$\begin{pmatrix} (.4) 10.16 \\ (1.3) 33.02 \end{pmatrix}$	$\begin{pmatrix} (.7) 17.8 \\ (.8) 20.32 \end{pmatrix}$	$\begin{pmatrix} (.7) \\ (1.3) \end{pmatrix}$
		$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$		$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) \\ (0) \end{pmatrix}$
		$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.1) 2.54 \\ (1.0) 25.4 \end{pmatrix}$	$\begin{pmatrix} (.2) 5.1 \\ (.4) 10.2 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (.7) 17.8 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.3) \\ (.2) \end{pmatrix}$
		$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.3) 7.62 \\ (2.5) 63.5 \end{pmatrix}$	$\begin{pmatrix} (.4) 10.2 \\ (.4) 10.2 \end{pmatrix}$	$\begin{pmatrix} (.3) 7.62 \\ (2.4) 61 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.6) \\ (.4) \end{pmatrix}$
					$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	
						$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) \\ (0) \end{pmatrix}$
1.5	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.8) 20.32 \\ (1.5) 38.1 \end{pmatrix}$	$\begin{pmatrix} (.5) \\ (2.0) \end{pmatrix}$
1.4 7	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.1) 2.54 \\ (.1) 2.54 \end{pmatrix}$		$\begin{pmatrix} (1.5) 38.1 \\ (1.0) 25.4 \end{pmatrix}$			
	$\begin{pmatrix} (1.0) 25.4 \\ (1.2) 30.5 \end{pmatrix}$	$\begin{pmatrix} (.9) 22.9 \\ (1.1) 27.9 \end{pmatrix}$	$\begin{pmatrix} (.1) 2.54 \\ (.8) 20.32 \end{pmatrix}$	$\begin{pmatrix} (1.5) 38.1 \\ (1.7) 43.2 \end{pmatrix}$	$\begin{pmatrix} (0) 0 \\ (0) 0 \end{pmatrix}$	$\begin{pmatrix} (.8) 20.32 \\ (2.0) 50.8 \end{pmatrix}$	$\begin{pmatrix} (1.3) \\ (1.5) \end{pmatrix}$
					$\begin{pmatrix} (1.0) 25.4 \\ (3.7) 94 \end{pmatrix}$		

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5, 90)₅

M. CYAN P907 RESIN	CYCOM 937	CIBA GEIGY 1M 2nd	NARMCO 107	CYCOM 982	NARMCO 109	CYCOM 919	
29.6	30.7	31.8	31.0	27.0	30.8	30.0	
$\frac{1.09}{.0054} .137$	$\frac{(.043) 1.09}{(.0054) .137}$	$\frac{(.045) 1.14}{(.0056) .142}$	$\frac{(.046) 1.17}{(.0058) .147}$	$\frac{(.041) 1.04}{(.0051) .132}$	$\frac{(.044) 1.12}{(.0055) .142}$	$\frac{(.027) .685}{(.039) .991}$	$\frac{(.04)}{}$
2) 5.1 2) 5.1	(.2) 5.1 (.1) 2.54	(0) 0 (0) 0	(.1) 2.54 (.5) 12.7	(.1) 2.54 (.7) 17.8	(.2) 5.1 (.2) 5.1	(.2) 5.1 (1.0) 25.4	(.1)
2) 5.1 4) 10.16	(.5) 12.7 (1.2) 30.5	(.2) 5.1 (.7) 17.8	(.3) 7.62 (.5) 12.7	(.5) 12.7 (1.0) 25.4	(.3) 7.62 (.6) 15.24	(.3) 7.62 (1.2) 30.5	(.1)
7) 17.8 3) 20.32	(.7) 17.8 (1.3) 33.02	(.3) 7.62 (1.4) 35.56	(.5) 12.7 (1.0) 25.4	(.7) 17.8 (1.3) 33.02	(.5) 12.7 (.6) 15.24	(.4) 10.16 (1.2) 30.5	(.1)
0 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(.1)
0 0	(.3) 7.62 (.2) 5.08	(0) 0 (0) 0	(.1) 2.54 (1.0) 25.4	(.1) 2.54 (1.2) 30.5	(.3) 7.62 (.1) 2.54	(.3) 7.62 (.7) 17.8	(.1)
0 0	(.6) 15.24 (.4) 10.16	(0) 0 (0) 0	(.1) 2.54 (.8) 20.32	(.3) 7.62 (3.0) 76.2	(.1) 2.54 (1.0) 25.4	(.1) 2.54 (1.2) 30.5	(.1)
0 0							
0 0	(0) 0 (0) 0		(0) 0 (0) 0	(0) 0		(0)	
3) 20.32 .5) 38.1	(.5) 12.7 (2.0) 50.4		(.8) 20.32 (.5) 12.7	(.8) 20.32 (1.2) 30.5	(0) 0 * (0) 0	(1.0) 38.1 (.5) 12.7	(.1)
						(1.0) (1.5) 38.1	
3) 20.32 .0) 50.8	(1.3) 33.02 (1.5) 38.1	(0) 0 (0) 0	(1.2) 30.5 (1.0) 25.4		(1.5) 38.1 (.8) 20.32		(.1)
		(0) 0 (0) 0					
		(0) 0 * (0) 0					(.1)
		(1.2) 30.5 (1.7) 43.2					

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CYCOM 982	NARMCO 109	CYCOM 919	FIBERDUX 914
27.0	30.8	30.0	23.5
$\frac{041) 1.04}{(.0051) .132}$	$\frac{(.044) 1.12}{(.0055) .142}$	$\frac{(.027) .685}{(.039) .991}$	$\frac{(.042) 1.07}{(.0052) .157}$
$\begin{pmatrix} .1 \\ .7 \end{pmatrix} \begin{matrix} 2.54 \\ 17.8 \end{matrix}$	$\begin{pmatrix} .2 \\ .2 \end{pmatrix} \begin{matrix} 5.1 \\ 5.1 \end{matrix}$	$\begin{pmatrix} .2 \\ 1.0 \end{pmatrix} \begin{matrix} 5.1 \\ 25.4 \end{matrix}$	$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 \\ 0 \end{matrix}$
$\begin{pmatrix} .5 \\ 1.0 \end{pmatrix} \begin{matrix} 12.7 \\ 25.4 \end{matrix}$	$\begin{pmatrix} .3 \\ .6 \end{pmatrix} \begin{matrix} 7.62 \\ 15.24 \end{matrix}$	$\begin{pmatrix} .3 \\ 1.2 \end{pmatrix} \begin{matrix} 7.62 \\ 30.5 \end{matrix}$	$\begin{pmatrix} .2 \\ .4 \end{pmatrix} \begin{matrix} 5.1 \\ 10.16 \end{matrix}$
$\begin{pmatrix} .7 \\ 1.3 \end{pmatrix} \begin{matrix} 17.8 \\ 33.02 \end{matrix}$	$\begin{pmatrix} .5 \\ .6 \end{pmatrix} \begin{matrix} 12.7 \\ 15.24 \end{matrix}$	$\begin{pmatrix} .4 \\ 1.2 \end{pmatrix} \begin{matrix} 10.16 \\ 30.5 \end{matrix}$	$\begin{pmatrix} .3 \\ .5 \end{pmatrix} \begin{matrix} 7.62 \\ 12.7 \end{matrix}$
$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 \\ 0 \end{matrix}$	$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 \\ 0 \end{matrix}$	$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 \\ 0 \end{matrix}$	$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 \\ 0 \end{matrix}$
$\begin{pmatrix} .1 \\ 1.2 \end{pmatrix} \begin{matrix} 2.54 \\ 30.5 \end{matrix}$	$\begin{pmatrix} .3 \\ .1 \end{pmatrix} \begin{matrix} 7.62 \\ 2.54 \end{matrix}$	$\begin{pmatrix} .3 \\ .7 \end{pmatrix} \begin{matrix} 7.62 \\ 17.8 \end{matrix}$	$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 \\ 0 \end{matrix}$
$\begin{pmatrix} .3 \\ 3.0 \end{pmatrix} \begin{matrix} 7.62 \\ 76.2 \end{matrix}$	$\begin{pmatrix} .1 \\ 1.0 \end{pmatrix} \begin{matrix} 2.54 \\ 25.4 \end{matrix}$	$\begin{pmatrix} .1 \\ 1.2 \end{pmatrix} \begin{matrix} 2.54 \\ 30.5 \end{matrix}$	$\begin{pmatrix} .3 \\ .7 \end{pmatrix} \begin{matrix} 7.62 \\ 17.8 \end{matrix}$
$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 \\ 0 \end{matrix}$		$\begin{pmatrix} 0 \end{pmatrix}$	
$\begin{pmatrix} 1.8 \\ 1.2 \end{pmatrix} \begin{matrix} 20.32 \\ 30.5 \end{matrix}$	$\begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{matrix} 0 * \\ 0 \end{matrix}$	$\begin{pmatrix} 1.0 \\ .5 \end{pmatrix} \begin{matrix} 38.1 \\ 12.7 \end{matrix}$	$\begin{pmatrix} .1 \\ .4 \end{pmatrix} \begin{matrix} 2.54 \\ 10.16 \end{matrix}$
		$\begin{pmatrix} 1.0 \\ 1.5 \end{pmatrix} \begin{matrix} 38.1 \\ 38.1 \end{matrix}$	
	$\begin{pmatrix} 1.5 \\ .8 \end{pmatrix} \begin{matrix} 38.1 \\ 20.32 \end{matrix}$		$\begin{pmatrix} .6 \\ .8 \end{pmatrix} \begin{matrix} 15.24 \\ 20.32 \end{matrix}$
			$\begin{pmatrix} .9 \\ .9 \end{pmatrix} \begin{matrix} 22.9 \\ 22.9 \end{matrix}$

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		NARMCO 5208 REFERENCE	5208 RESIN RICH	5208 RESIN POOR	A
(1.25") 31.7 mm SUPPORT 5/8" ROUND IMPACT HEAD	RESIN CONTENT	27.7	29.9	24.6	
	TOTAL THICKNESS (IN) mm PLY THICKNESS (IN) mm	$\frac{(.042) 1.07}{(.0052) .13}$	$\frac{(.044) 1.12}{(.0055) .14}$	$\frac{(.040) 1.02}{(.0050) .127}$	$\frac{(.040) 1.02}{(.0050) .127}$
	(10" LB) X 1.13 Joules Y	(.2) 5.1 * (.7) 17.8	(.1) 2.54 (1.0) 25.4	(0) 0 (0) 0	
	(20" LB) X 2.26 Joules Y	(.3) 7.62 (1.2) 30.5	(.3) 7.62 (1.5) 38	(.2) 5.1 (1.2) 30.5	
	(30" LB) X 3.39 Joules Y	(.4) 10.2 (1.2) 30.5	(.5) 12.7 (1.5) 25.4	(.6) 15.24 (1.5) 38.1	
(3.75") 92.2 mm SUPPORT (5/8") 15.8 mm ROUND IMPACT HEAD (5/8") 15.8 mm FLAT IMPACT HEAD	(10" LB) X 1.13 Joules Y	(0) 0 (0) 0	(.1) 2.54 (.5) 12.7	(0) 0 (0) 0	
	(20" LB) X 2.26 Joules Y	(.2) 5.1 (1.5) 38	(.1) 2.54 (1.0) 25.4	(.1) 2.54 (1.0) 25.4	
	(30" LB) X 3.39 Joules Y	(.3) 7.62 (3.0) 76.2	(.5) 12.7 (3.5) 88.9	(.3) 7.62 (3.0) 76.2	
	(40" LB) X 4.52 Joules Y	(0) 0 (0) 0	(0) 0 (0) 0		
	(50" LB) X 5.65 Joules Y	(0) 0 (0) 0	(1.0) 25.4 (2.5) 63.5	(0) 0 (0) 0	
	(60" LB) X 6.78 Joules Y	(1.1) 27.9 (1.1) 27.9	(1.0) 25.4 (2.5) 63.5	(.6) 15.24 (.5) 12.7	
	(70" LB) X 7.91 Joules Y				
	(80" LB) X 9.04 Joules Y	(1.2) 30.5 (3.7) 93.9	(1.7) 43.2 (2.2) 55.9	(.7) 17.8 (2.0) 50.8	
	(90" LB) X 10.17 Joules Y				
	(100" LB) X 11.3 Joules Y				
	(120" LB) X 13.56 Joules Y				

* NOTE: UNITS ARE (INCHES) MILLIMETERS IN THE X AND Y DIRECTION OF AREA OF DAMAGE

②

TABLE 3 (Cont'd)

5208 SIN POOR	A. M. CYAN BP907	U. S. POLY #1	NARMCO 95995	AIR LOG #1	HEXC #1
24.6	29.8	29.2	32.7	28.0	28.
<u>(.040) 1.02</u> (.0050) .127	<u>(.040) 1.02</u> (0.061) .15	<u>(.040) 1.02</u> (.0050) .127	<u>(.041) 1.04</u> (.0051) .132	<u>(.048) 1.22</u> (.0060) .152	<u>(.043) 1.</u> (.0054)
(0) 0 (0) 0	(0) 0 (0) 0	(.2) 5.1 (.1) 2.54	(.2) 5.1 (.8) 20.32	(0) 0 (0) 0	(0) 0 (0) 0
(.2) 5.1 (1.2) 30.5	(.3) 7.62 (1.0) 25.4	(.3) 7.62 (.2) 5.1	(.3) 7.62 (2.0) 50.8		(.3) 7 (.2) 5
(.6) 15.24 (1.5) 38.1	(.6) 15.24 (.8) 20.32	(.4) 10.16 (.7) 17.8	(.7) 17.8 (2.0) 50.8		(.3) 7 (.3) 7
(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0
(.1) 2.54 (1.0) 25.4	(.1) 2.54 (.1) 2.54	(.2) 5.08 (.1) 2.54	(0) 0 (0) 0	(.1) 2.54 (.2) 5.1	(.4) 1 (.4) 1
(.3) 7.62 (3.0) 76.2	(.3) 7.62 (.3) 7.62	(.4) 10.16 (.6) 15.24	(.4) 10.2 (1.7) 43.2	(.4) 10.2 (.5) 12.7	(.4) 1 (1.0)
(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0	(0) 0 (0) 0		(0) 0 (0) 0
(.6) 15.24 (.5) 12.7	(1.3) 33.02 (.7) 17.8	(0) 0 (0) 0	(1.5) 38.1 (1.3) 33.02	(0) 0 (0) 0	(0) 0 (0) 0
(.7) 17.8 (2.0) 50.8	(1.5) 38.1 (.5) 12.7	(1.5) 38.1 (.5) 12.7	(1.4) 35.56 (1.5) 38.1	(.7) 17.8 (.4) 10.16	(1.1) (.7) 1

OF AREA OF DAMAGE

ont'd)

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OG	HEXCEL #1	CIBA GEIGY #2	CIBA GEIGY #3	CIBA GEIGY #1 (RERUN)	FIBERITE 976
0	28.3	28.0	24.6	28.9	29.6
22).152	<u>(.043) 1.09</u> (.0054) .137	<u>(.042) 1.07</u> (.0052) .132	<u>(.042) 1.07</u> (.0052) .132	<u>(.042) 1.07</u> (.0052) .132	<u>(.046) 1.17</u> (.0058) .1
	(0) 0 (0) 0		(0) 0 (0) 0		(0) 0 (0) 0
	(.3) 7.62 (.2) 5.1		(.2) 5.1 (1.0) 25.4		(.2) 5.1 (1.2) 30.5
	(.3) 7.62 (.3) 7.62		(.3) 7.62 (1.5) 38.1		(.4) 10.2 (1.2) 30.5
	(0) 0 (0) 0	(0) 0 (0) 0			(0) 0 (0) 0
.54 .1	(.4) 10.16 (.4) 10.16				(.2) 5.1 (.8) 20.32
0.2 2.7	(.4) 10.16 (1.0) 25.4				(.2) 5.1 (2.0) 50.4
					(0) 0 (0) 0
	(0) 0 (0) 0				(0) 0 (0) 0
	(0) 0 (0) 0	(0) 0 (0) 0		(0) 0 (0) 0	(0) 0 (0) 0
			(0) 0 (0) 0	(0) 0 (0) 0	(.2) 5.1 (.3) 7.62
7.8 .16	(1.1) 27.94 (.7) 17.78	(.4) 10.16	(0) 0 (0) 0	(0) 0 (0) 0	(.1) 2.54 (.3) 7.62
			(0) 0 (0))	(0) 0 (0))	(.8) 20.3 (2.0) 5.0

3

4

	CIBA GEIGY #2	CIBA GEIGY #3	CIBA GEIGY #1 (RERUN)	FIBERITE 976
	28.0	24.6	28.9	29.6
7	$\frac{(.042) 1.07}{(.0052) .132}$	$\frac{(.042) 1.07}{(.0052) .132}$	$\frac{(.042) 1.07}{(.0052) .132}$	$\frac{(.046) 1.17}{(.0058) .147}$
		(0) 0 (0) 0		(0) 0 (0) 0
		(.2) 5.1 (1.0) 25.4		(.2) 5.1 (1.2) 30.5
		(.3) 7.62 (1.5) 38.1		(.4) 10.2 (1.2) 30.5
	(0) 0 (0) 0			(0) 0 (0) 0
				(.2) 5.1 (.8) 20.32
				(.2) 5.1 (2.0) 50.4
				(0) 0 (0) 0
				(0) 0 (0) 0
	(0) 0 (0) 0		(0) 0 (0) 0	(0) 0 (0) 0
		(0) 0 (0) 0	(0) 0 (0) 0	(.2) 5.1 (.3) 7.62
	(.4) 10.16	(0) 0 (0) 0	(0) 0 (0) 0	(.1) 2.54 (.3) 7.62
		(0) 0 (0))	(0) 0 (0))	(.8) 20.32 (2.0) 5.08

2.2.3 Rheometric Constant Speed Impact Test

The Rheometric Impact Tester gave another useful means of evaluation of the impact characteristics of the materials. The test machine gathered data during the test event, recorded a printed record of a load deflection curve, and calculated and printed the calculation of initial slope of the stress strain curve (which is a measure of the material modulus of elasticity), energy in joules (inch pounds), absorbed at first sign of failure, and the total energy absorbed, in joules (inch pounds), during the total test event.

The Rheometric Impact Tester (see Figure 4) used a constant speed overwhelming force impact ram with a 15.9 mm (5/8 inch) round impact nose that penetrated the specimen. The specimens were securely clamped to the machine across a 50.8 mm (2-inch) diameter support hole that was centered to the path of the impact head. The tests were all conducted at a constant speed of 76.2 m (3000 inches) per minute. A load and deflection curve was plotted for each material during the penetration impact. The events recorded and calculated by the Rheometric Impact Tester are shown in Figure 5 and are described below:

- (1). This is the time that the impact head first makes contact with the specimen.
- (2). This is a low point on the approximate straight line portion of the stress/strain curve as selected by the machine operator after completion of the test.
- (3). This is the high point on the approximate straight line portion of the stress/strain curve as selected by the machine operator. The data is not reduced to account for the 50.8 mm (2 inch) diameter rigid support and, thus, is not recorded as a true modulus calculation.
- (4). Yield is the time that the stress/strain deviates from an approximate straight line and is considered the point of initial impact damage to the specimen. The area, in joules (inch pounds), under the curve from point 1 to 4, is calculated as the energy absorbed at first sign of panel damage or failure.
- (5). Ultimate is the deflection where maximum load is achieved during the impact penetration event. Major fiber breakage has probably occurred by this time.
- (6). Total is the deflection where the load has reduced to a near constant level and impact penetration is complete. It probably represents the drag on the edge of the plunger as the penetration continued to full depth of the impact stroke. The area, in joules (inch pounds), under the curve point 1 to 6 is calculated as the total energy absorbed by the panel for this impact test.



RHEOMETRICS, INC.

High Rate Impact Tester

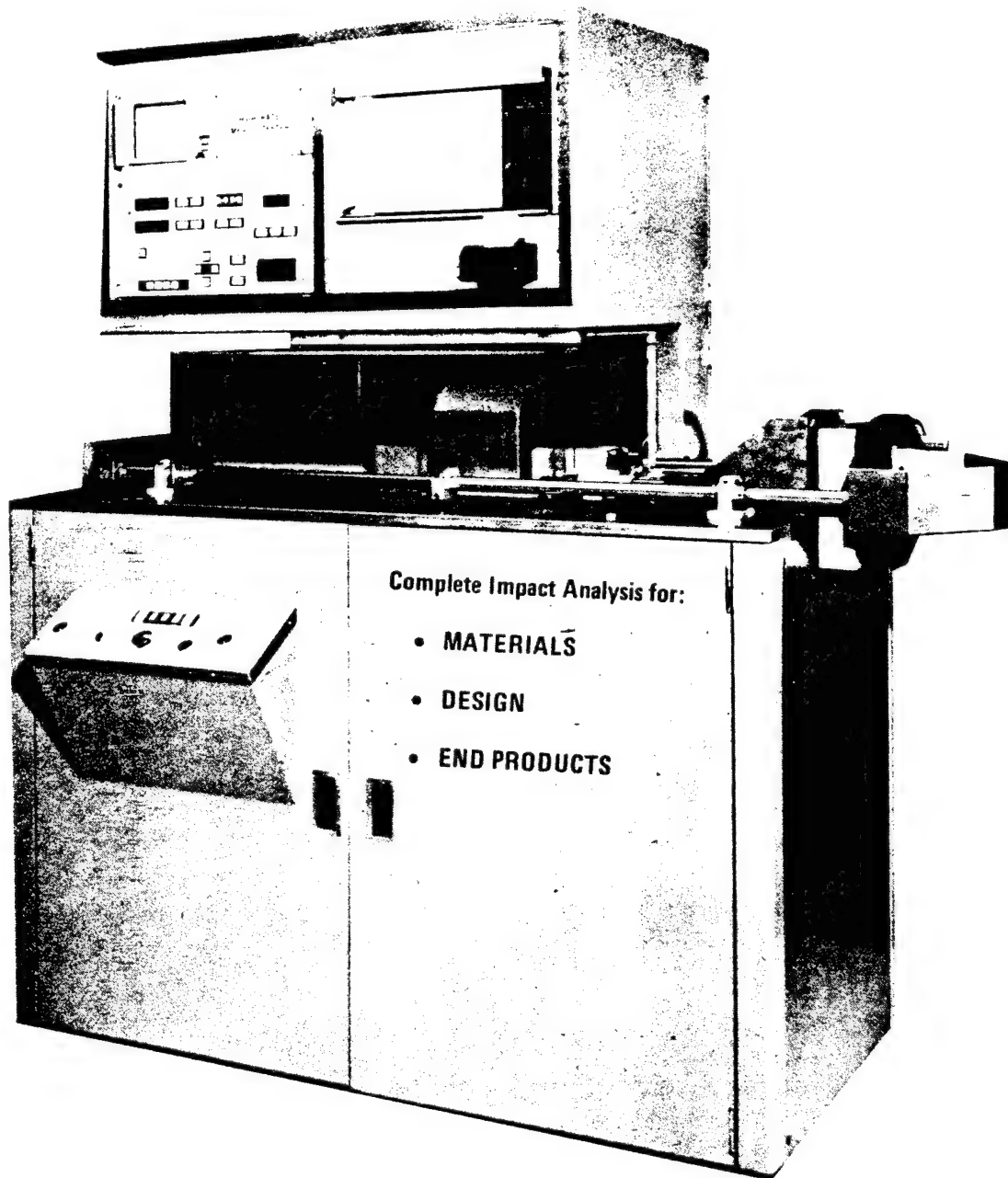


FIGURE 4. RHEOMETRIC CONSTANT SPEED IMPACT TESTER

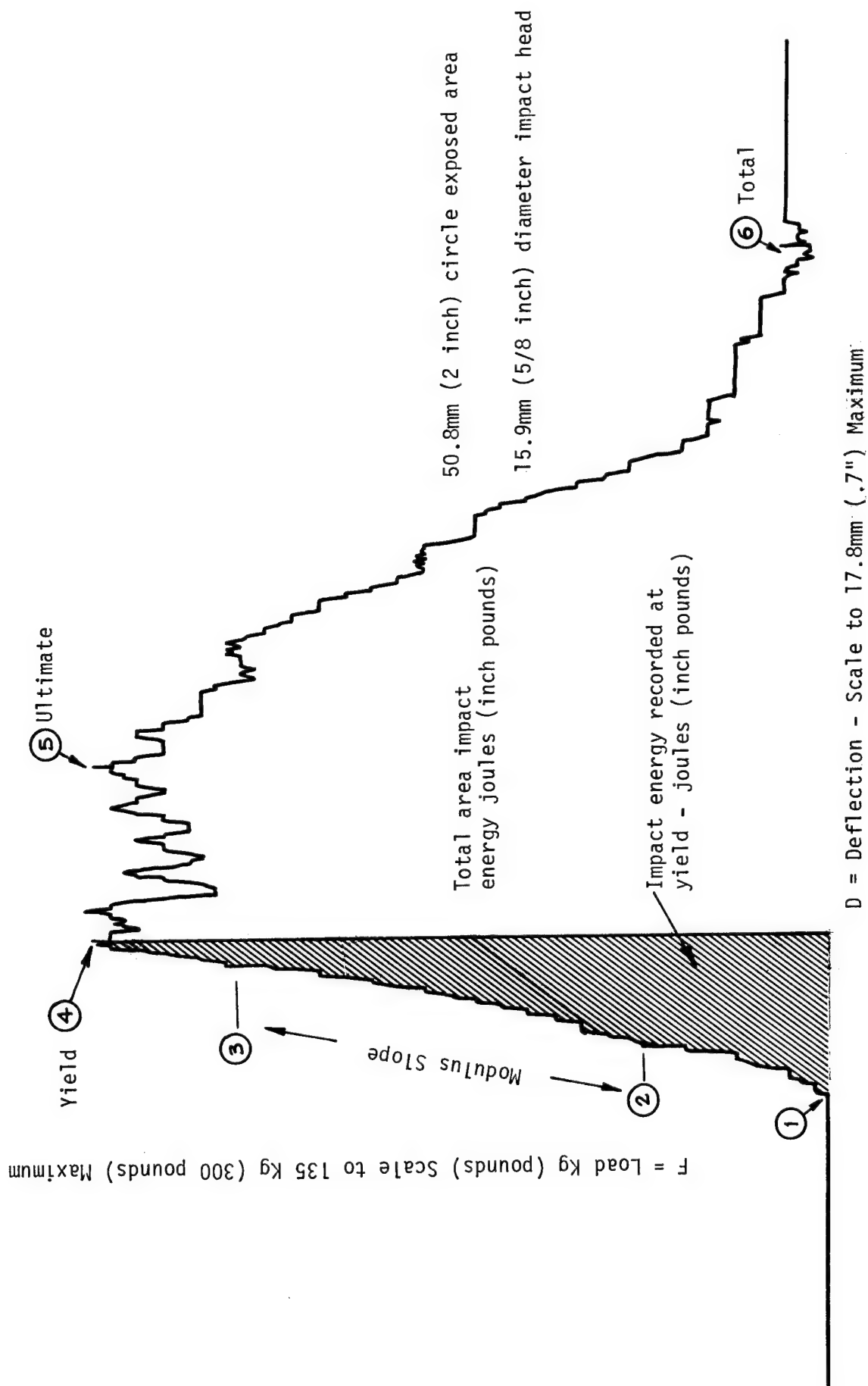


FIGURE 5. RHEOMETRICS CONSTANT SPEED IMPACT CHART

A summary of the Rheometric calculations of slope of the stress-strain curve, energy absorbed at initial impact failure and total energy absorbed by impact penetration is shown in Table 4. Individual traces for the ten materials, studied are presented in Appendix 3.

2.3. TASK 3 - LAMINATE MECHANICAL PROPERTIES

Each material received from each of the suppliers was processed into laminate form for both impact and mechanical property tests, as presented in Task 2, during a single curing cycle. All flexural and all short beam shear coupons were cut from 16 ply 0° fiber orientation panels. Flexural coupon size and formula for calculation of maximum stress and modulus of elasticity are shown in Figure 6.

Short beam shear coupon size and formula for calculation of shear stress is shown in Figure 7.

All tensile and compression coupons were cut from 6 ply 0° fiber orientation panels. The composite coupons were autoclave bonded to 3.8 cm (1 1/2") thick 368 Kg/M³ (23 pound/ft³) 3.2 mm (1/8 inch) cell aluminum honeycomb using a 121°C (250°F) curing FM73 adhesive film from American Cyanamid Corp. Steel skins were bonded to the opposite surface of the honeycomb and sized to force failure, whether tension or compression loading, into the composite skin. Tension and compression coupon configuration, test procedure, and formula for calculation of stress at failure and modulus of elasticity are shown in Figure 8.

Quality control tests for each panel used for flexural, shear, tensile, and compression tests include a thickness measurement and resin and void content obtained by using the hot nitric acid digestion process.

All mechanical property tests were conducted at room temperature on an Instron test machine. A summary of all mechanical property tests is presented in Table 5.

2.4 TASK 4 - THICK LAMINATE IMPACT RESISTANCE

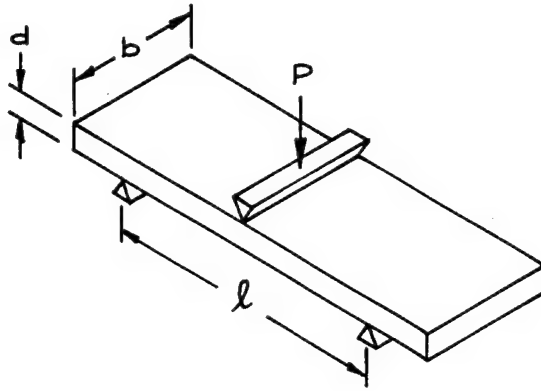
Each material received from each of the suppliers was processed into a thick 48 ply impact panel by procedures detailed in Task 2 and in a single curing cycle along with the thin impact panels of Task 2 and the mechanical property panels of Task 3. The laminate 48 ply pattern was the same for all panels.

$$(\underline{+45/0_2}/\underline{+45/0_2}/\underline{+45/0/90}/\underline{+45/0_2}/\underline{+45/0_2}/\underline{+45/0/90})_s$$

Each panel was cut to one 12.5cm x 12.5cm (5" x 5") and one 12.5cm x 25cm (5" x 10") coupon and delivered to NASA for thick laminate impact studies.

TABLE 4
RHEOMETRIC IMPACT PENETRATION TEST RESULTS
76.2 M/Min
(3000 Inches/Minute)
8 Ply (0, \pm 45°, 90°)_s Thornel Fiber Pattern

MATERIAL	SLOPE OF STRESS/STRAIN CURVE (IN LBS/IN) JOULES/mm	LOAD (POUNDS) kg	YIELD DEFLECTION, (IN) mm	ENERGY ABSORBED, (IN LBS) JOULES	LOAD, (POUNDS) Kg	TOTAL DEFLECTION, (IN) mm	ENERGY ABSORBED, (IN LBS) JOULES
Narmco 5208	(3205) 14.1	(191) 86	(0.12) 3.05	(9.4) 1.06	(8) 3.6	(0.56) 14.22	(41.0) 4.63
Ciba Geigy #4	(4000) 17.60	(347) 157	(0.16) 4.06	(23.9) 2.70	(37) 16.7	(0.55) 13.97	(83.3) 9.42
Ciba Geigy Fiberdur 920	(2809) 12.36	(218) 99.1	(0.11) 2.79	(9.05) 1.02	(37) 16.7	(0.55) 13.97	(60.0) 6.79
American Cyanamid BP/907	(2889) 12.71	(224) 101	(0.12) 3.05	(19.8) 1.22	(11) 5	(0.56) 14.22	(64.7) 7.31
U.S. Polymeric #2	(3205) 14.10	(253) 114	(0.12) 3.05	(13.9) 1.57	(11) 4.9	(0.55) 13.97	(67.7) 7.09
Narmco X1114	(3399) 14.95	(316) 143	(0.21) 5.33	(36.2) 4.09	(0) 0	(0.57) 14.48	(88.9) 10.0
American Cyanamid BP-982	(3121) 13.73	(199) 90.1	(0.14) 3.56	(14.2) 1.61	(27) 12.2	(0.50) 12.7	(53.3) 6.02
Ciba Geigy #1M	(3852) 16.95	(243) 110	(0.12) 3.05	(11.9) 1.35	(19) 8.6	(0.57) 14.48	(70.4) 7.96
Narmco X-107	(3553) 15.63	(246) 111	(0.15) 3.81	(18.5) 2.89	(27) 12.2	(0.56) 14.22	(67.6) 6.73
American Cyanamid BP-919	(3131) 13.78	(248) 112	(0.13) 3.30	(13.1) 1.48	(3) 1.3	(0.52) 13.21	(56.6) 6.39



Flexural strength and modulus was calculated as the arithmetic mean for a minimum of three specimens.

$$\text{Flexural Strength} = \frac{3PL}{2bd^2}$$

$$\text{Flexural Modulus of Elasticity} = \frac{L^3M}{4bd^3}$$

Where: P = The ultimate failure load in Kg (pounds to the nearest Kg (pound)).

L = The span length in cm (inches) to the nearest .13 mm (0.005 inch).

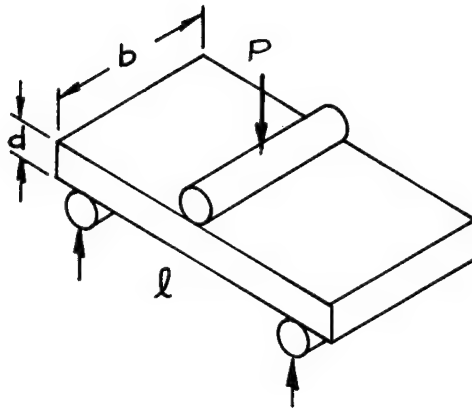
b = The specimen width in mm (inches) to the nearest .025mm (0.001 inch).

d = The specimen thickness in mm (inches) to the nearest .013mm (0.0005 inch).

M = The initial slope of the load-deflection curve in Kg/meter (pounds per inch) to three significant figures.

The span to thickness ratio was 32 ± 2 to 1.

FIGURE 6. FLEXURAL SPECIMEN



Short beam shear strength was calculated as the arithmetic mean of a minimum of three specimens.

$$\text{Horizontal Shear Strength} = \frac{3P}{4bd}$$

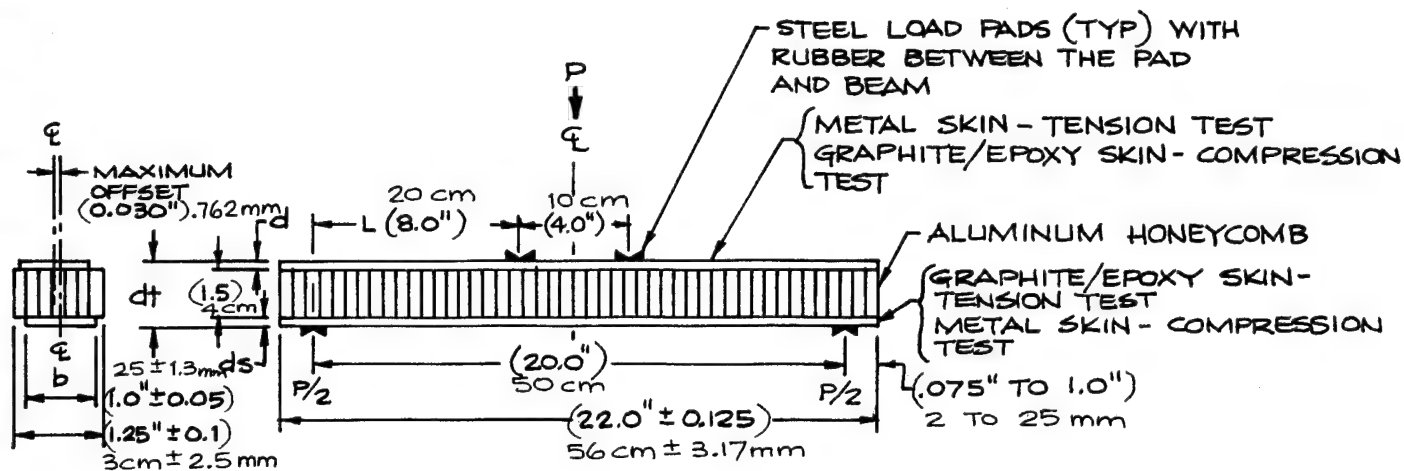
Where: P = The shear failure load in Kg (pounds) to the nearest Kg (pound).

b = The specimen width in mm (inches) to the nearest .0254mm (0.001 inch).

d = The specimen thickness in mm (inches) to the nearest .127 mm (0.005 inch).

The span to thickness ratio was between 3 1/2 and 4 to 1.

FIGURE 7. SHORT BEAM SHEAR SPECIMEN



- NOTES: (1) Metal skins were 25.4mm (1.00 inch) wide, 3.17mm (.125 inch) thick and 55.9cm (22.0 inches) length and made of 4130 steel hardened to a minimum of $9.64 \times 10^8 \text{ N/m}^2$ (140,000 psi).
- (2) The honeycomb core was 38mm (1.5 inch) thick 5052-H39 nonperforated 3.17mm (1/8 inch) cell, .152 mm (0.006 inch) foil gage aluminum.
- (3) Composite skins were 25.4mm (1.00 inch) wide, .76mm (.03 inch) thick and 55.9cm (22 inches) long.

Longitudinal tensile and compression strength and modulus of elasticity were calculated as the arithmetic mean of a minimum of three specimens.

$$St \text{ and } Sc - \text{Tensile Strength and Compressive Strength} = \frac{PL}{bd(2dt-d-ds)}$$

$$Et \text{ or } Ec - \text{Tensile Modulus and Compressive Modulus} = \frac{(St \text{ or } Sc) M}{P}$$

Where: St = Ultimate tensile strength.

Sc = Ultimate compressive strength.

P = Ultimate failure load in Kg (pounds) to the nearest Kg (pound).

L = Moment arm between applied load and reaction support.

d = Specimen thickness in mm (inches) to the nearest .0127mm (0.0005 inch).

b = Specimen width in mm (inches) to the nearest .0254mm (0.001 inch).

dt = Overall thickness of sandwich in mm (inches) to the nearest .254mm (0.01 inch), measure at the center.

ds = Thickness of the steel facing in mm (inches) to the nearest .254mm (0.01 inch).

Et = Initial tensile modulus.

Ec = Initial compressive modulus.

M = The slope of the load/strain curve at the straight line portion nearest the origin in Kg per meter per meter (pounds per inch per inch) to three significant digits.

FIGURE 8. SANDWICH BEAM TENSILE AND COMPRESSION SPECIMENS

①

	Narmco 5208/T300	Am. Cyan. BP907	U. S. Poly #1	Narmco 95995	Air Log. #1	Ciba Geigy #1	Hexcel #1	Ciba Geigy #2	
CURED PROP.									
Flex. Str.(ksi)	(310)	(334)	(223)	(284)	(126)	(333)	(269)	(239)	(200)
N/M ² X 10 ⁸	21.35	23.01	15.36	19.57	8.68	22.94	18.53	16.47	18.53
Flex. Mod.(msi)	(19.0)	(20.7)	(21.0)	(20.0)	(16.7)	(21.0)	(17.9)	(18.5)	(20.0)
N/M ² X 10 ⁹	130.91	142.62	144.69	137.80	115.06	144.69	123.33	127.46	130.91
Shear Str.(ksi)	(19.0)	(15.0)	(12.2)	(18.1)	(8.3)	(13.1)	(12.9)	(9.2)	(12.2)
N/M ² X 10 ⁶	130.91	103.35	84.06	124.71	57.19	90.26	88.88	63.39	84.06
Resin Cont. %	28.0	28.1	27.6	31.4	32.9	24.3	28.3	24.4	24.4
Void Cont. %	1.0	1.3	0.5	.3	4.9	.5	-0-	1.1	1.1
Tens. Str.(ksi)	(218)	(247)	(267)	(206)	(238)	(326)	(273)	(277)	(310)
N/M ² X 10 ⁸	15.02	17.02	18.39	14.19	16.39	22.46	18.81	19.08	21.35
Tens. Mod.(msi)	(19.0)	(18.9)	(19.5)	(16.6)	(16.7)	(22.5)	(20.4)	(21.5)	(20.0)
N/M ² X 10 ⁹	130.91	130.22	134.35	114.37	115.06	155.02	140.55	148.13	130.91
Comp. Str.(ksi)	(210)	(178)	(93)	(190)	(88)	(226)	(116)	(148)	(210)
N/M ² X 10 ⁸	14.47	12.26	6.40	13.09	6.06	15.57	7.99	10.19	14.47
Comp. Mod.(msi)	(18.0)	(16.3)	(19.7)	(15.0)	(15.7)	(21.0)	(17.5)	(19.2)	(20.0)
N/M ² X 10 ⁹	124.02	112.31	135.73	103.35	108.17	144.69	120.57	132.29	124.02
Resin Cont. %	28.0	31.7	24.6	33.0	27.0	25.7	28.8	25.0	25.0
Void Cont. %	1.	.6	1.3	.3	3.1	.9	-1.0	.6	1.1
SUPPLIER DATA									
MATRIX PROP.									
Tens. Str.(ksi)	(8.3)	(13)	(7.0)	(10.8)	(6.9)	(14.4)	(7.7)	(15.)	(13)
N/M ² X 10 ⁶	57.2	89.47	48.23	74.41	47.54	99.22	53.05	103.35	94.02
Tens. Mod.(ksi)	(580)	(450)	(340)	(542)	(250)	(644)	(320)	(480)	(480)
N/M ² X 10 ⁸	39.96	31.00	23.43	37.34	17.22	44.37	22.05	33.07	33.07
Elong. Yield %	1.5	4.8	7.0					5.5	
Elong. Failure %	1.		19.	2.4	8.0	8.7	7.0	7.0	7.0
Density	1.267	1.22	1.23	*	*	1.270	*	1.219	1.219

2

TABLE 5
MATERIAL PROPERTY TESTS

Hexcel #1	Ciba Geigy #2	Ciba Geigy #3	Fiberite 976 HY-E	Fibredux 920	Hexcel #2	Ciba Geigy #4	Narmco X1114	Narmco X108/34A	U.S. Poly #2	5208 Slow Cure	Fiberite 920
269)	(239)	(262)	(307)	(321)	(191)	(298.)	(183)	(318)	(322.0)	(337)	(305)
18.53	16.47	18.06	21.15	22.12	13.16	20.53	12.61	21.91	22.18	23.22	21.0
17.9)	(18.5)	(20.0)	(20.5)	(20.5)	(21.2)	(21.5)	(17.5)	(25.3)	(23.5)	(23.5)	(19.5)
123.33	127.46	137.80	141.24	141.24	146.07	148.13	120.57	174.32	161.91	161.91	135.0
12.9)	(9.2)	(12.3)	(17.6)	(14.1)	(13.5)	(16.2)	(7.9)	(19.6)	(15.8)	(19.8)	(15.6)
88.88	63.39	84.75	121.26	97.15	93.01	111.62	54.43	135.04	108.86	136.42	107.0
28.3	24.4	24.8	26.5	37.2	27.1	25.0	36.7	23.1	24.0	25.1	31.9
-0-	1.1	1.5	1.0	.7	1.7	1.7	3.5*	1.1*	1.5*	1.0	0.5
273)	(277)	(311)	(230)	(281)	(246)	(278)	(251)	(257)	(307)	(276)	(252)
18.81	19.08	21.43	15.85	19.36	16.95	19.15	17.29	17.71	21.15	19.02	17.3
20.4)	(21.5)	(22.0)	(18.5)	(20.6)	(19.0)	(18.0)	(21.2)	(21.0)	(23.9)	(21.7)	(21.5)
140.55	148.13	151.58	127.46	141.93	130.91	124.02	146.07	144.69	164.67	149.51	145.0
116)	(148)	(214)	(159)	(167)	(153)	(65)	(69)	(155)	(237)	(281)	(176)
7.99	10.19	14.74	10.95	11.51	10.54	11.37	4.75	10.68	16.33	19.36	12.0
17.5)	(19.2)	(20.0)	(17.0)	(17.9)	(17.4)	(20.0)	(15.5)	(19.5)	(19.4)	(19.5)	(16.4)
120.57	132.29	137.80	117.13	123.33	119.89	137.80	106.79	134.35	135.67	134.35	112.0
28.8	25.0	23.4		33.6	28.9	28.7	30.8	24.0	24.8	25.2	33.8
-1.0	.6	1.3		1.3	1.5	0.9	4.7*	1.3*	0.9*	1.3	0.5
(7.7)	(15.)	(13.7)	(9.0)	(10.9)	(6.5)	(13.0)	(4.5)		(13.6)	(6.3)	(10.9)
53.05	103.35	94.39	62.01	75.10	44.78	89.57	31.00		93.70	43.41	75.1
(320)	(480)	(484)	(400)	(453)	(370)	(482)	(240)			(580)	(453)
22.05	33.07	33.35	27.56	31.21	25.49	33.21	16.54			39.96	31.2
	5.5					---			---		---
7.0	7.0	7.0	5.	4.1	1.9	4.7	6.0		8.0		4.0
*	1.219	1.234	1.28	1.239		1.221	*	*		1.267	1.21

3

5208 Slow Cure	Fibredux 920 Low Resin	Ciba Geigy #111	Am. Cyan BP-907 Low Resin	Am. Cyan 919	Am. Cyan 937	Ciba Geigy 1M 2nd	Narmco 107	Narmco 109	Am Cyan. 982	Fibredux 914
37)	(305)	(310)	(327)	(368)	(397)	(413)	(324)	(279)	(284)	(344)
3.22	21.01	21.36	22.53	25.35	27.35	28.45	22.32	19.22	19.57	23.70
3.5)	(19.7)	(20.5)	(18.6)	(23.3)	(26.2)	(23.0)	(17.8)	(17.8)	(20.8)	(20.6)
51.91	135.73	141.24	128.15	160.54	180.52	158.47	122.64	122.64	143.31	141.93
9.8)	(15.6)	(10.5)	(14.7)	(14.9)	(15.7)	(9.3)	(13.5)	(12.4)	(16.7)	(18.0)
36.42	107.48	72.34	101.28	102.66	108.17	64.08	93.01	84.06	115.06	124.02
5.1	31.9	26.1	29.8	30.3	29.5	26.6	36.3	34.5	26.8	23.5
.0	0.5	-0.41	0.7	-2.7	-0.8	-0.2	1.9*	2.4*	0.5	1.2
6)	(252)	(281)	(248)	(259)	(248)	(276)	(232)	(243)	(243)	(270)
1.02	17.36	19.36	17.09	17.84	17.09	19.02	15.98	16.74	16.74	18.60
7)	(21.1)	(22.8)	(20.0)	(20.6)	(20.9)	(19.2)	(19.7)	(19.2)	(20.7)	(20.7)
9.51	145.38	157.09	137.80	141.93	144.00	132.29	135.73	132.29	142.62	142.62
1)	(176)	(236)	(203)	(194)	(220)	(181)	(109)	(94)	(258)	(232)
.36	12.13	16.26	13.99	13.37	15.16	12.47	7.51	6.48	17.78	15.98
5)	(16.4)	(17.7)	(17.6)	(18.6)	(17.9)	(17.6)	(17.5)	(16.7)	(17.2)	(17.6)
4.35	112.99	121.95	121.95	128.15	123.33	121.26	120.57	115.06	118.51	121.26
.2	33.8	27.6	31.4	31.7	31.7	32.8	29.8	33.5	27.0	
.3	0.5	-0.45	0.3	-2.8	-1.4	-1.0	1.5*	1.1*	0.7	
.3)	(10.9)		(13)							(7.2)
.41	75.10		89.57							49.61
0)	(453)		(450)							(580)
.96	31.21		31.00							39.96
	---		4.8							
	4.1									1.4
67	1.215	1.27	1.22	1.33	1.26	1.27			1.25	---

Quality control tests for each panel include resin content determination by using the hot nitric acid digestion process and calculation of % void and % fiber volume.

A summary of all thick laminate quality control tests is presented in Table 6.

2.5 TASK 5 - DISCUSSION OF TEST RESULTS

Discussion of results for tests conducted on candidate tough resin systems are presented below. Twenty-three different resin systems supplied by seven different manufacturers were tested. Three material systems were tested at high and low resin content and one material had a second batch tested to verify the first batch test results. In all, a total of thirty different panels were evaluated during the course of the program.

2.5.1 Thin Laminate Impact Vs. Resin Matrix Properties

The thin laminate impact study is based on the Gardner Impact Test results reported in Table 3 and in Appendix 1 and the Rheometric constant speed impact penetration test results reported in Table 4 and Appendix 3.

2.5.1.1 Gardner Impact Specimens

The criteria for evaluation of the Gardner impact results are:

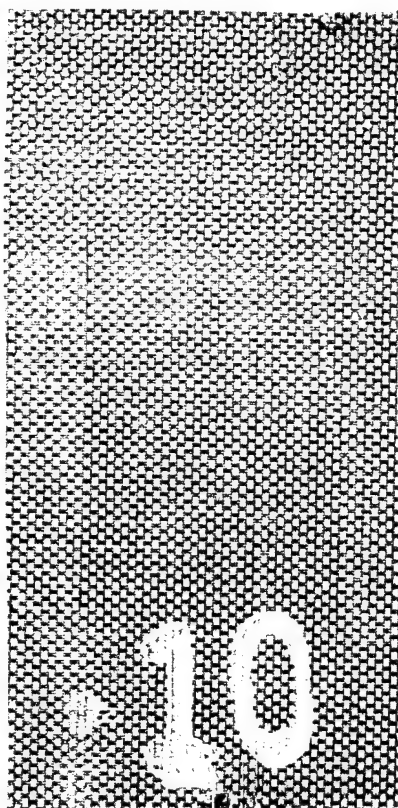
- a. Level of impact - (inch pounds) joules
- b. Visual evidence and extent of front surface damage.
- c. Visual evidence and extent of back surface damage.
- d. Area of internal damage recorded by C-scan NDT.

Almost all of the materials evaluated proved to have superior thin laminate impact resistance compared to the baseline Narmco 5208/T-300 material. This was an encouraging result and verified that the material suppliers do have the technical knowledge and capability to improve the toughness of current composite materials. The amount of visible damage from the Gardner Impact Tester is recorded for both the impact side and the back side of each impact panel in Appendix 1. Appendix 1 also includes a record of the C-scan recordings of internal damage and other detail information on resin and laminate properties. Figures 9, 10, 11 12 and 13 show the visual evidence at 2x magnification of damage on the back side of the Narmco 5208/T-300 material and four "toughened" materials. Note that all of the toughened systems exhibit much less visible impact damage. In every case the visible damage is more extensive on the back side than the impact side of the panel as recorded in Appendix 1.

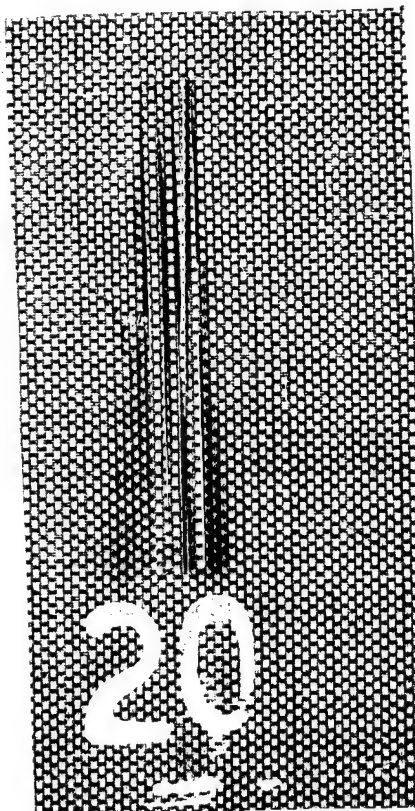
TABLE 6
48 PLY IMPACT PANEL QUALITY CONTROL TESTS

MATERIAL	RESIN CONTENT-%	VOID CONTENT-%	FIBER VOLUME-%
American Cyanamid BP-907	30.2	1.2	61
U.S. Polymeric #1	27.6	0.6	64.5
Narmco 95995	37.6	0.6	54.4
Air Logistics #1	33.9	3.1*	56.8
Ciba Geigy #1	28.7	0.8	63.8
Hexcel #1	32.6	-0.7*	60.5
Ciba Geigy #2	27.6	-1.3	65.6
Ciba Geigy #3	33.9	2.2	57.2
Fiberite HY-E 976	29.5	1.7	62.6
Fiberdux 920	39.8	3.0*	50.9
Hexcel #2	34.1	2.4*	57.0
Ciba Geigy #4	38.5	0.7	52.5
Narmco X1114	38.1	4.4*	51.8
Narmco X-108/34A	26.6	1.0*	67.2
U.S. Polymeric #2	27.4	1.0*	65.2
Narmco 5208 Slow Cure	28.2	0.1	64.9
Fiberdux 920 Low Resin	33.9	0.8	57.9
Ciba Geigy #1M	31.0	-1.8*	62.1
American Cyanamid BP-907 Low Resin	37.2	2.0	54.0
American Cyanamid 919	34.4	-3.3*	60.1
American Cyanamid 937	37.2	-1.6	56.0
Ciba Geigy #1M 2nd	43.2	1.0*	49.5
Narmco 107	39.3	2.3	51.8
Narmco 109	37.0	2.4	54.0
American Cyanamid 982	32.2	2.1	59.3
Fiberdux 914	23.2	2.1	68.6

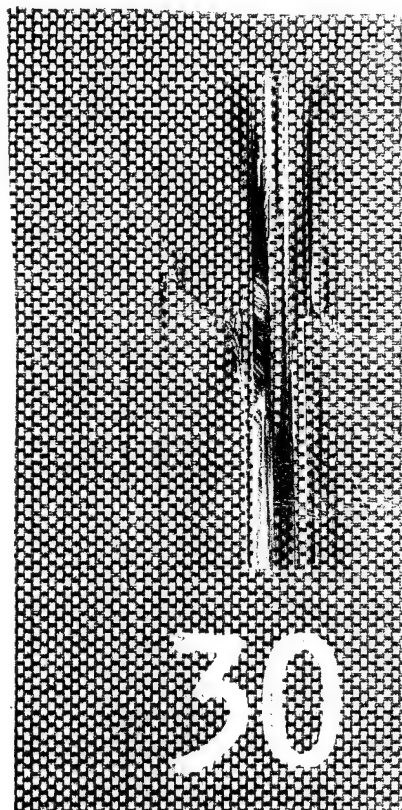
* Assumed resin density of 1.267 gm/cc



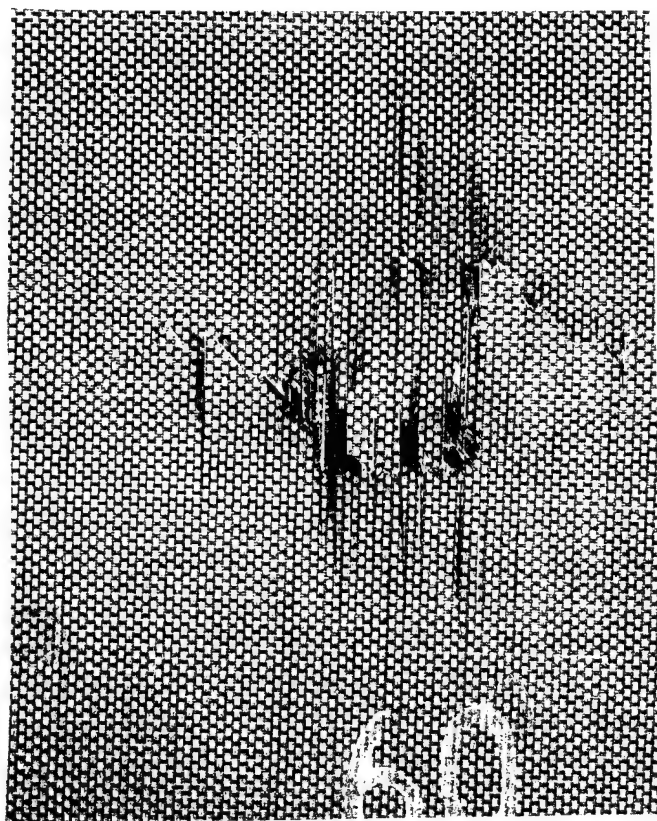
(10 inch-pounds)
1.13 Joules



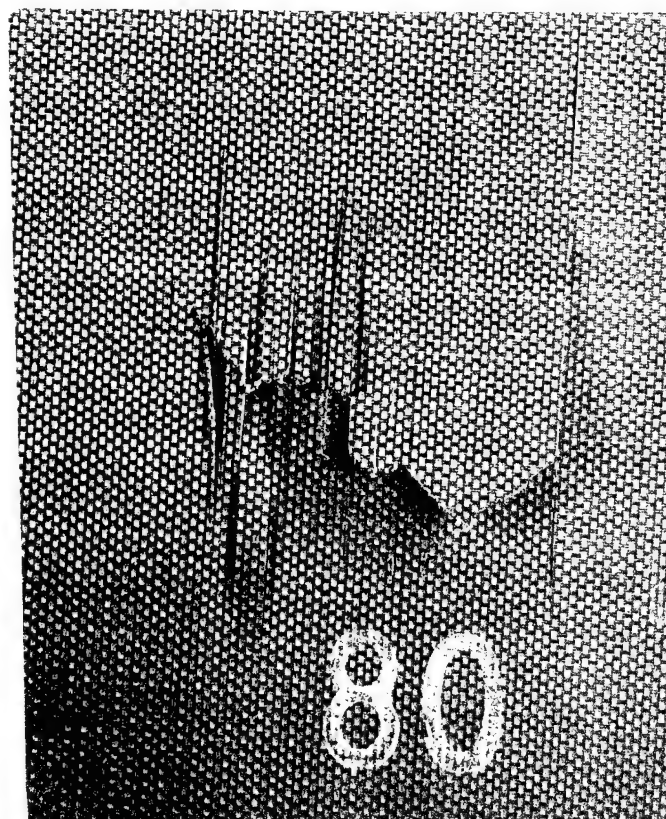
(20 inch-pounds)
2.26 Joules



(30 inch-pounds)
3.39 Joules



(60 inch-pounds)
6.78 Joules



(80 inch-pounds)
9.04 Joules

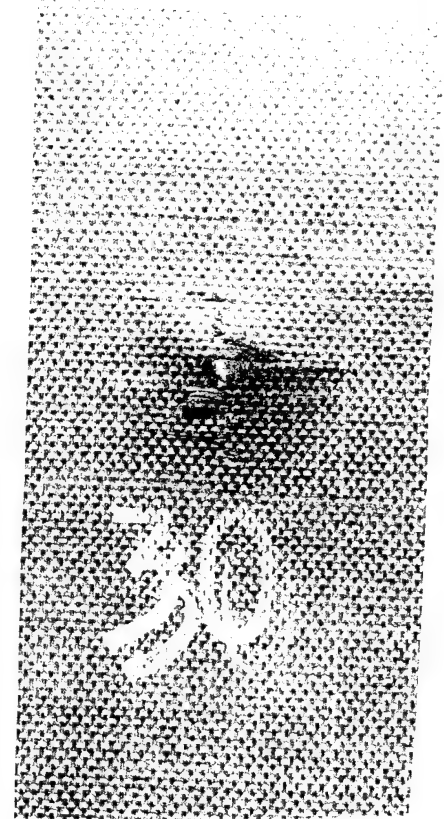
FIGURE 9. VISIBLE IMPACT DAMAGE ON BACK SIDE (0, \pm 45, 90)_s
5208 REFERENCE LAMINATE



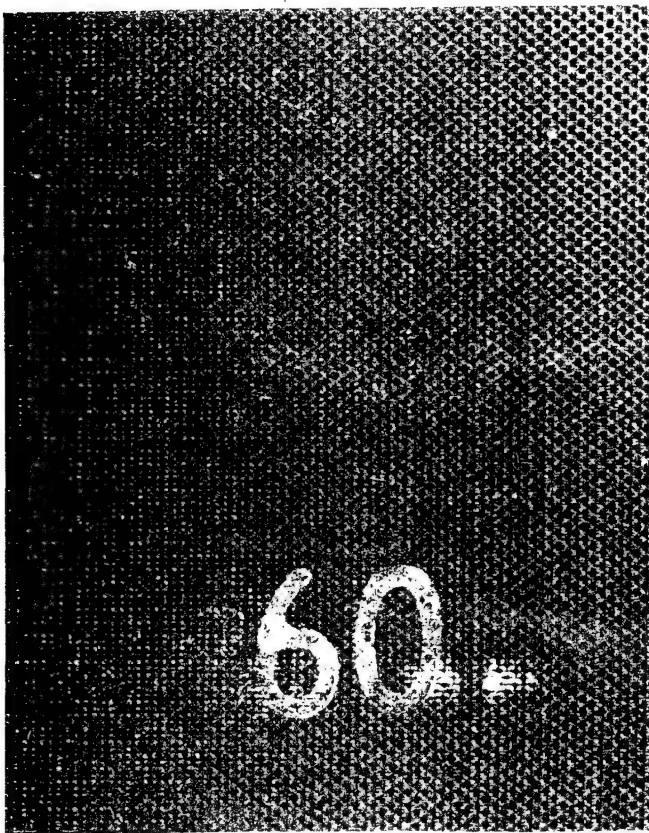
(10 inch-pounds)
1.13 Joules



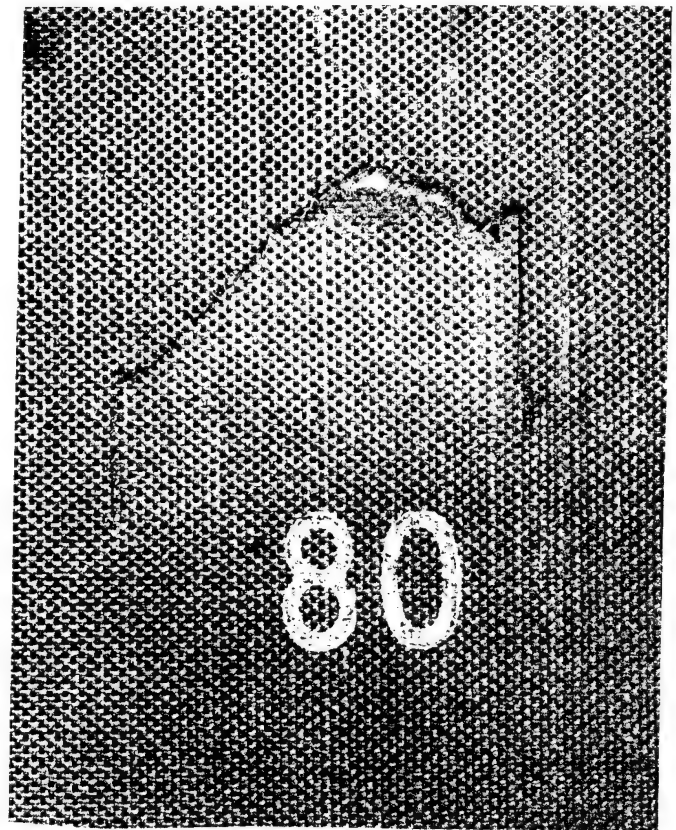
(20 inch-pounds)
2.26 Joules



(30 inch-pounds)
3.39 Joules

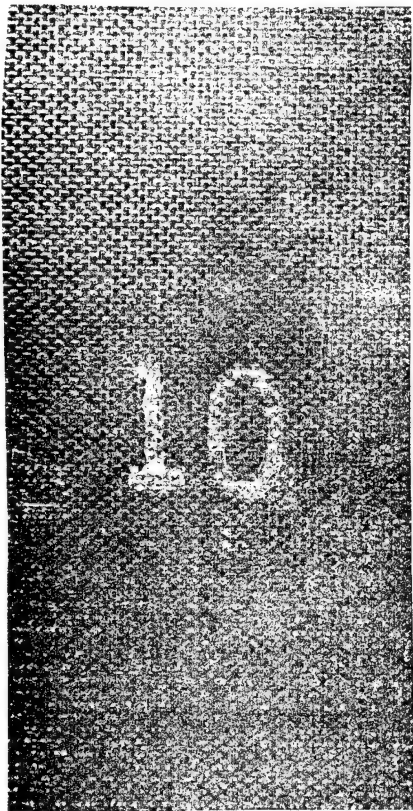


(60 inch-pounds)
6.78 Joules

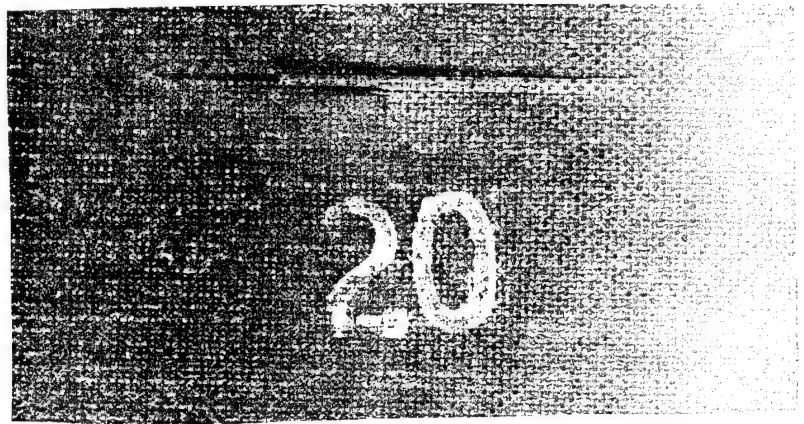


(80 inch-pounds)
9.04 Joules

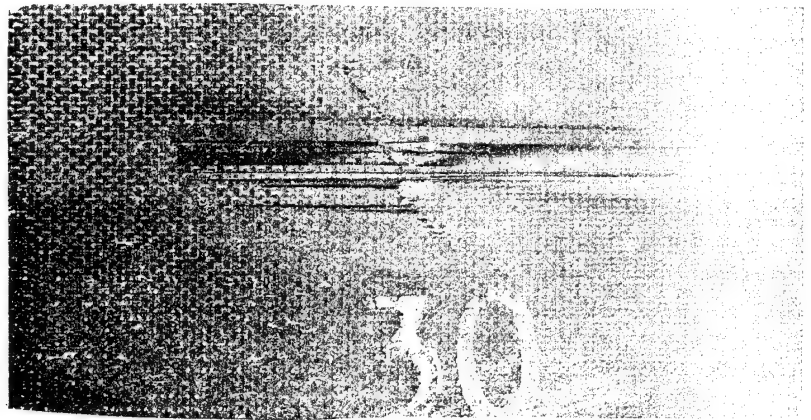
FIGURE 10. VISIBLE IMPACT DAMAGE ON BACK SIDE (0, \pm 45, 90)_s
HEXCEL #1 LAMINATE



(10 inch-pounds)
1.13 Joules



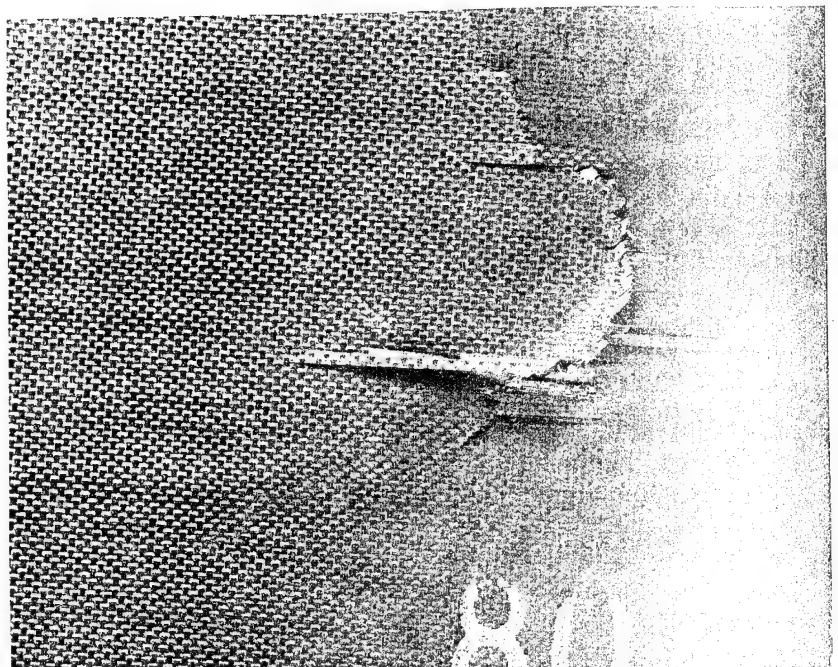
(20 inch-pounds)
2.26 Joules



(30 inch-pounds)
3.39 Joules

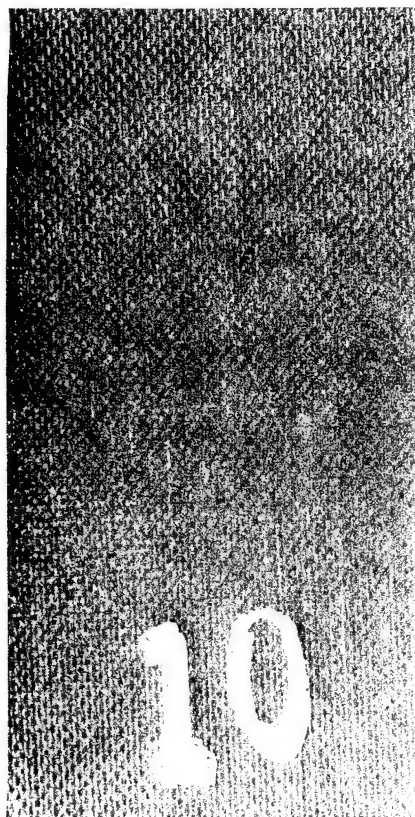


(60 inch-pounds)
6.78 Joules

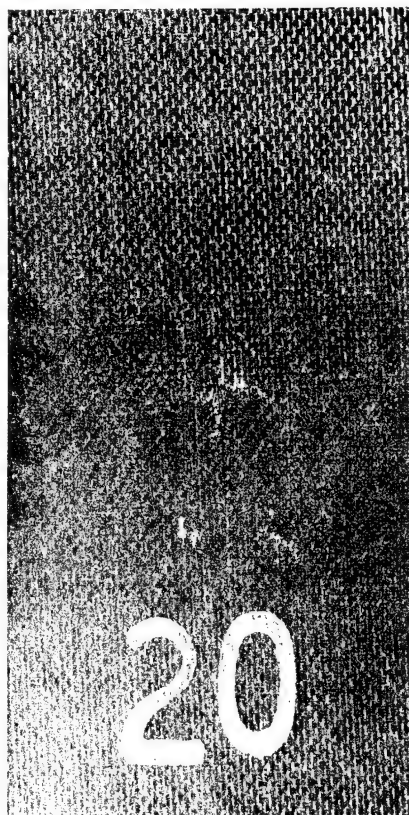


(80 inch-pounds)
9.04 Joules

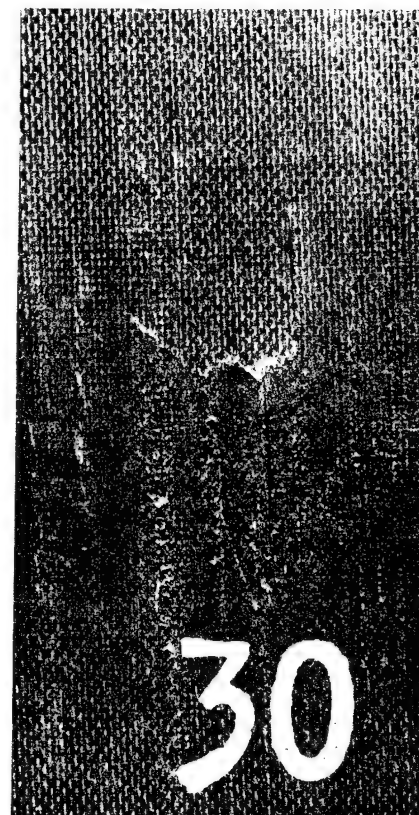
FIGURE 11. VISIBLE IMPACT DAMAGE ON BACK SIDE (0, \pm 45, 90)_s
CIBA GEIGY #4 LAMINATE



(10 inch-pounds)
1.13 Joules



(20 inch-pounds)
2.26 Joules



(30 inch-pounds)
3.39 Joules

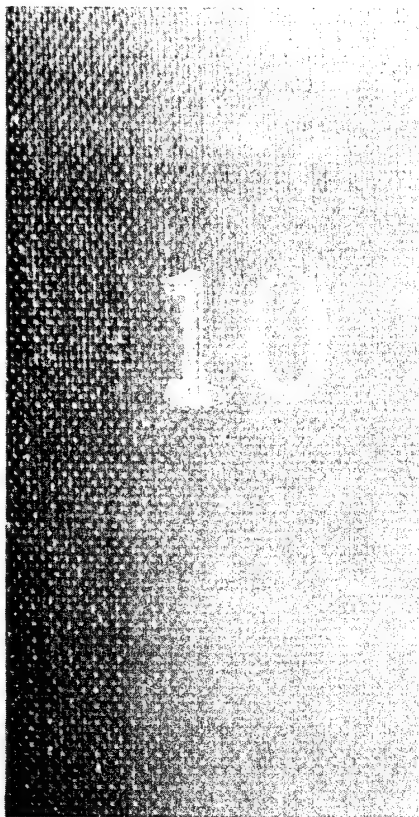


(60 inch-pounds)
6.78 Joules

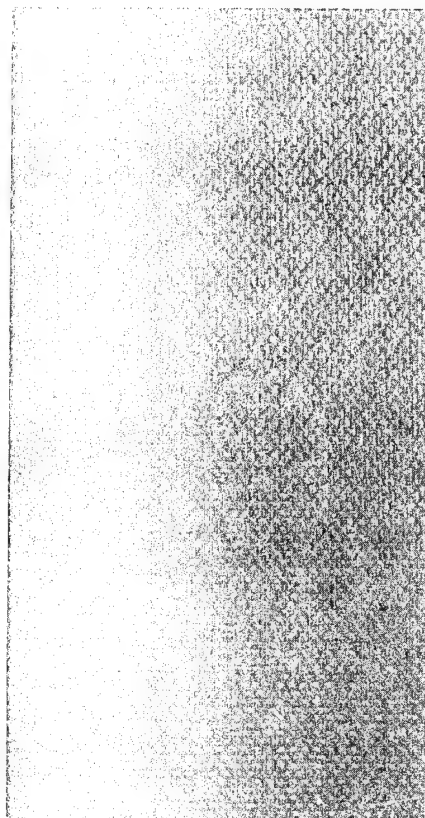


(80 inch-pounds)
9.04 Joules

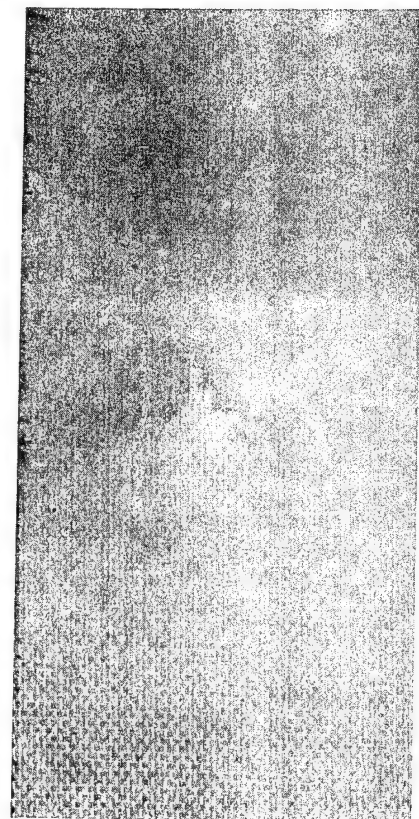
FIGURE 12. VISIBLE IMPACT DAMAGE ON BACK SIDE (0, + 45, 90)s
BP907 LAMINATE



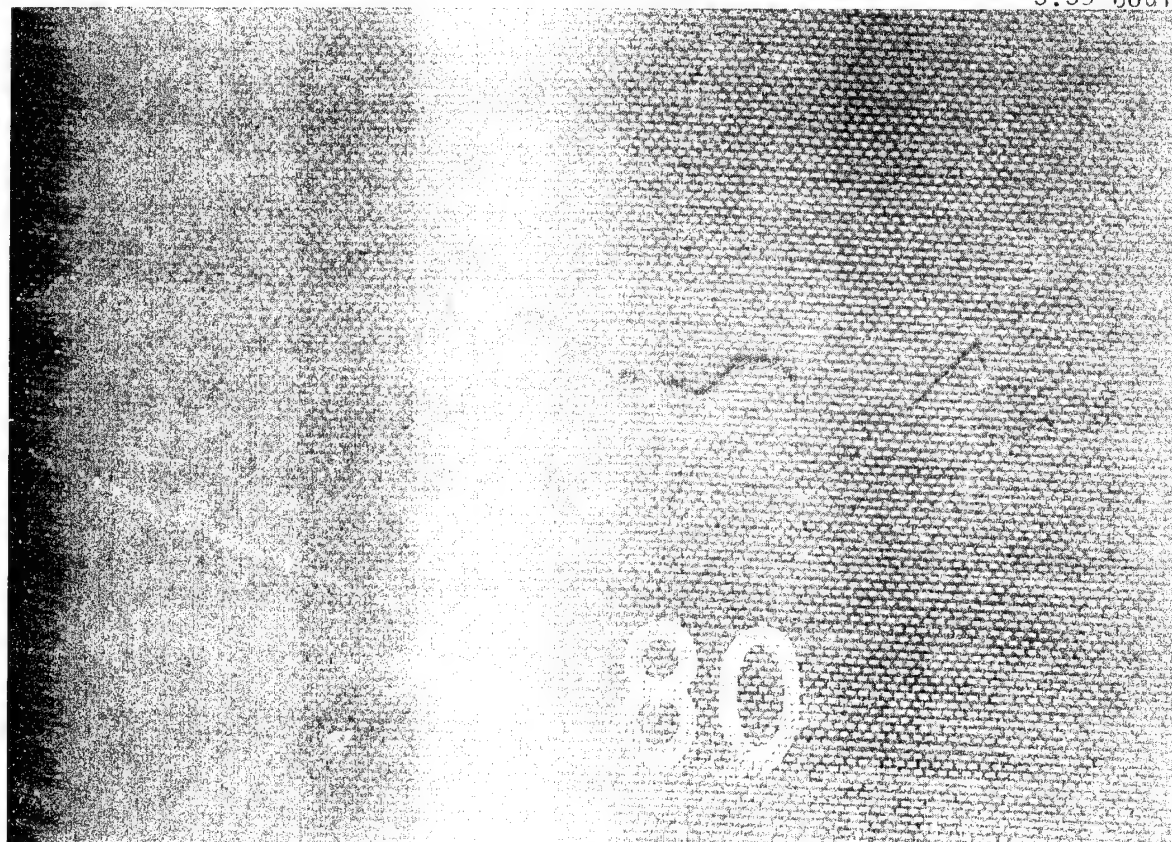
(10 inch-pounds)
1.13 Joules



(20 inch-pounds)
2.26 Joules



(30 inch-pounds)
3.39 Joules



(80 inch-pounds)
9.04 Joules

FIGURE 13. VISIBLE IMPACT DAMAGE ON BACK SIDE (0, \pm 45, 90)s
FIBERDUX 926 LAMINATE

Figures 14, 15, 16, 17, 18 and 19 show cross sectional photographs at varying magnifications of damage caused by impact blows of 3.39 joules (30) and 9.04 joules (80 in pounds) to Narmco 5208, BP-907 and Ciba Geigy #4 eight ply laminates.

The 5208 mode of impact failure, at these load levels of impact, is noticeably different than the "toughened" materials. In the immediate area at impact, photographs No. 14A and 15A, there is considerable splintering and severe delamination between plies of material and thru-the-thickness ply cracking of the resin matrix, best shown in photograph No. 14C. As we move away from the direct impact, photographs 14B and 15B, the failure is mainly delamination in the resin matrix between plies of material. At the periphery of the damaged area, the failure at the tip of the crack appears in the resin interface between plies of laminate, photograph 15C.

The tough resin systems, BP-907 and Ciba Geigy #4, in the immediate area of impact, photographs No. 16A, 17A & B, 18A & B and 19A and B show far less splintering and minimal delamination between plies of material even when relatively close to the impact point. At the periphery of the damaged area, the failure at the tip of the crack appears in the resin matrix within a ply of material, photograph No. 19C.

The C-scan NDT process has proven very beneficial in determining the extent of internal damage from impact. Examples of back and front side damage vs internal area C-scan recorded damage is shown for Narmco 5208/T-300 and five toughened resin systems in Figures 20, 21, 22, 23, 24 and 25. It is evident that the visual surface damage, front or back, does not describe the extent of the real amount of damage contained in the panels. This holds true for both brittle (5208) and toughened resin systems although the extent of damage is less for the tough resins.

A review of the C-scan records of impact damage at various levels for Narmco 5208 and several toughened resins is presented in Figure 26. The extent of damage from impact is less in the toughened material systems.

Aluminum 2024 T-3 alloy panels were impacted by the Gardner Equipment at the same levels as the graphite/epoxy laminates. The 0.98 mm (0.040") aluminum was the same approximate weight as the graphite/epoxy panels. Photographs of the results of these tests are shown in Appendix II.

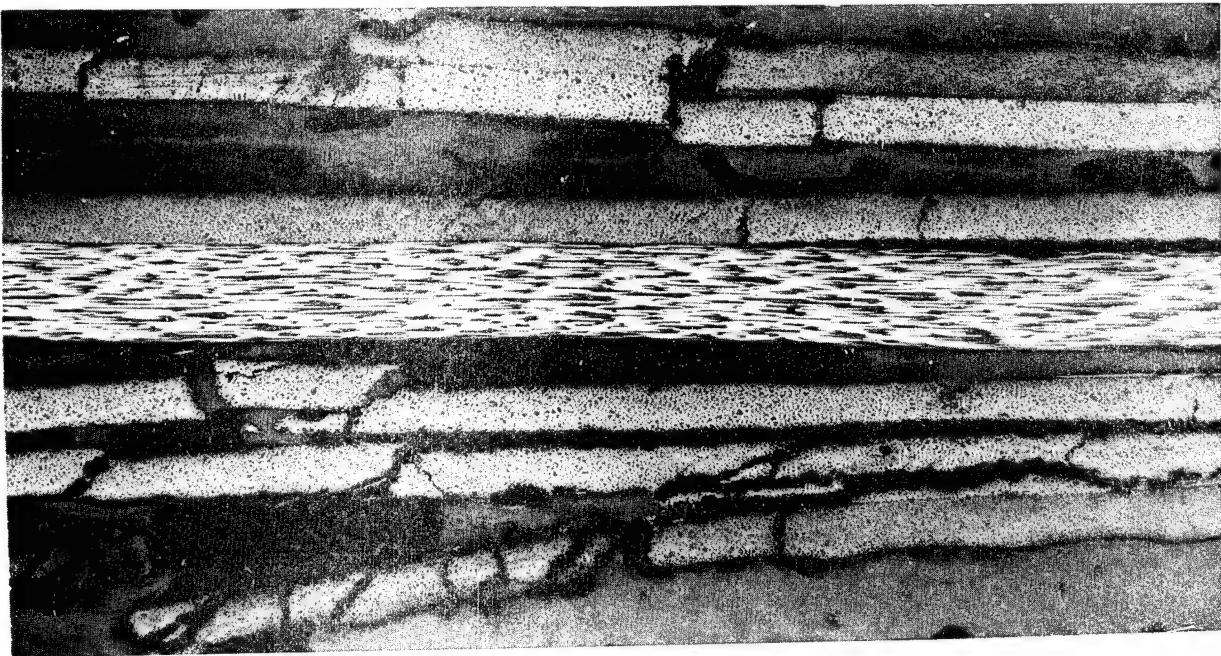
The aluminum specimens yielded under low 10 in lb. Gardner impact and made permanent dents in the skin. The improved graphite/epoxy materials showed no visual damage and only slight internal damage by C-scan examination from the same 10 in. lbs. impact load.

At higher impact loads, to 100 in lbs., the aluminum skins still yielded and took large permanent dents, but no puncture. Most improved graphite panels showed broken fibers on the front and back surface and visual signs of puncture of the surface.

C



B



A

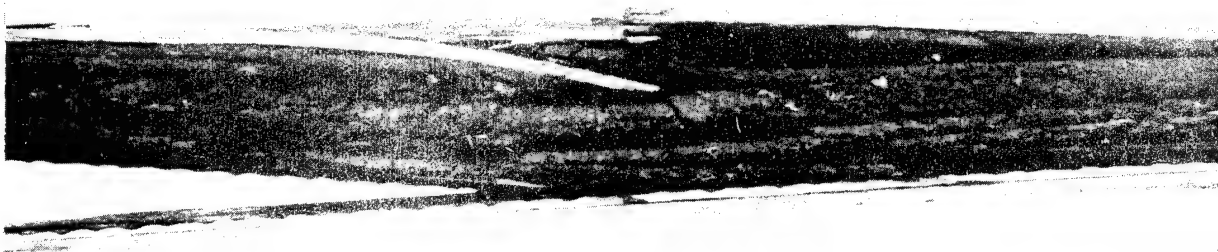
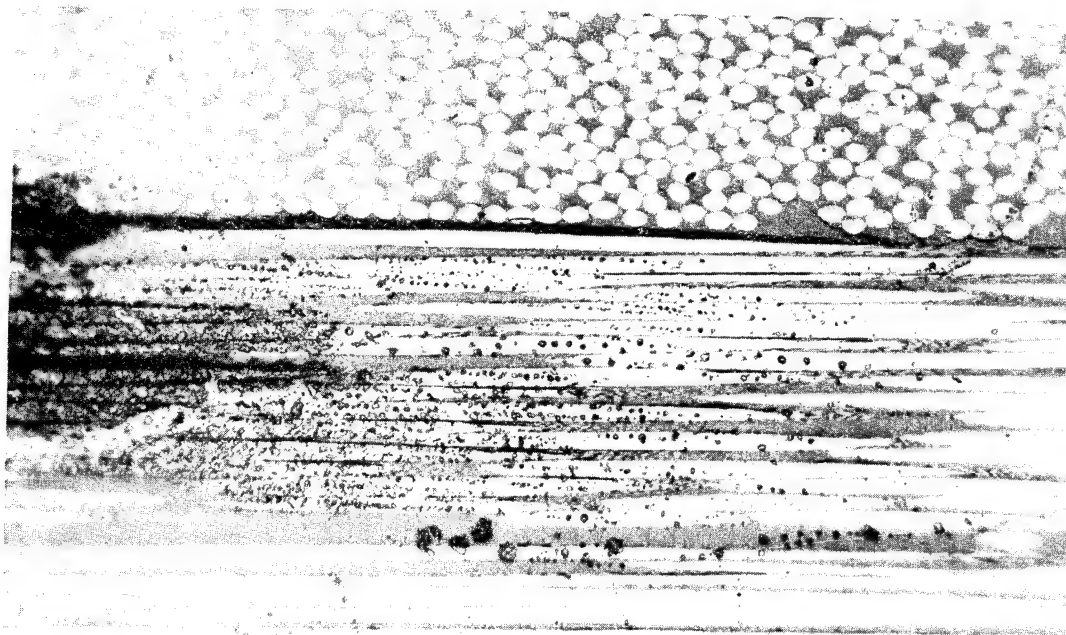


FIGURE 14. NARMCO 5208 3.39 JOULES (30 INCH POUNDS) GARDNER IMPACT

C



B



A

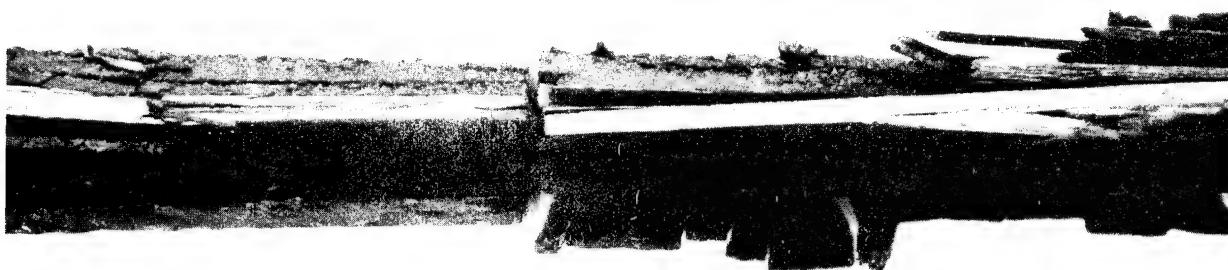
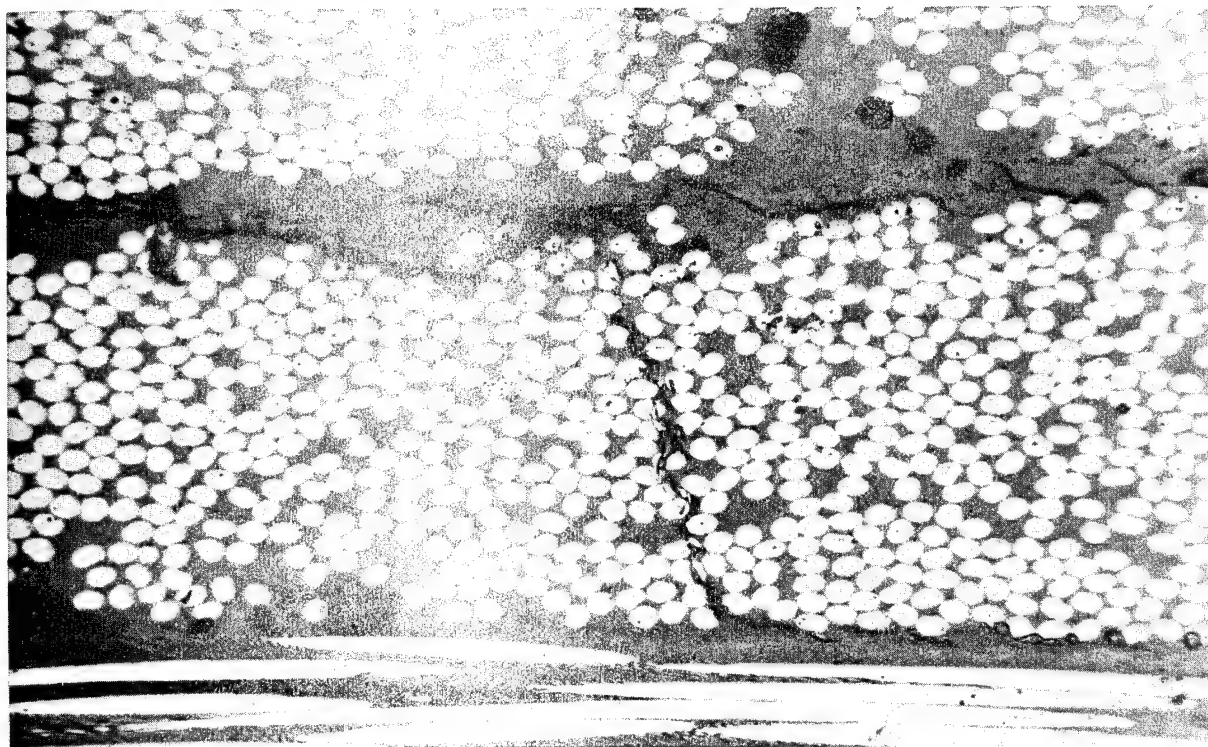
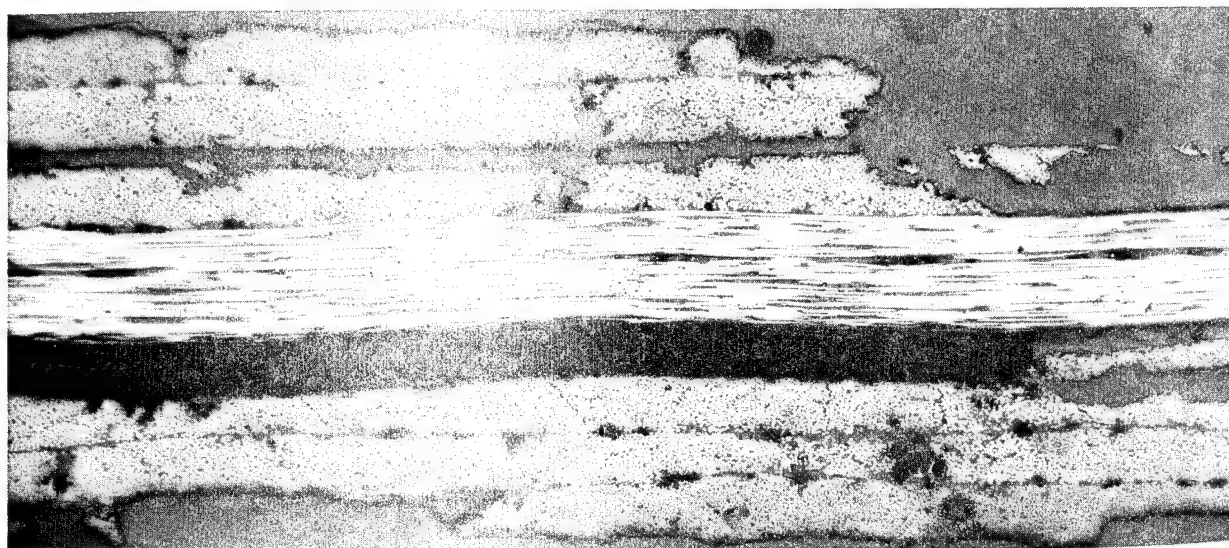


FIGURE 15. NARMCO 5208 9.04 JOULES (80 INCH POUNDS) GARDNER IMPACT

C



B

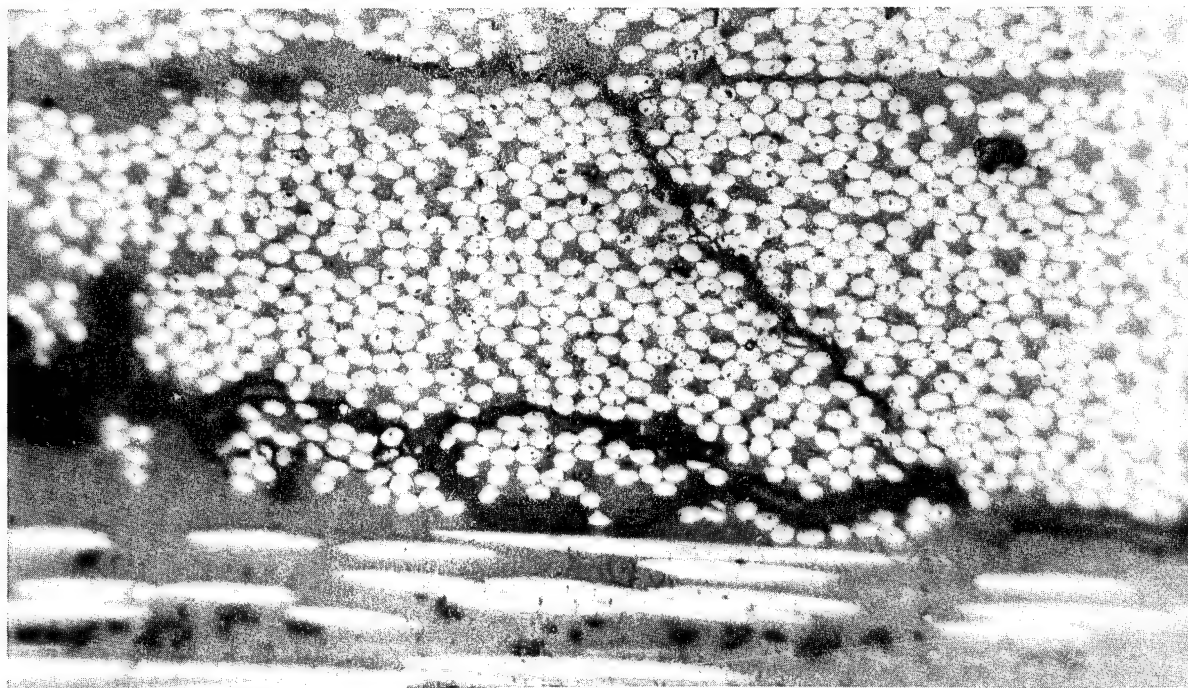


A

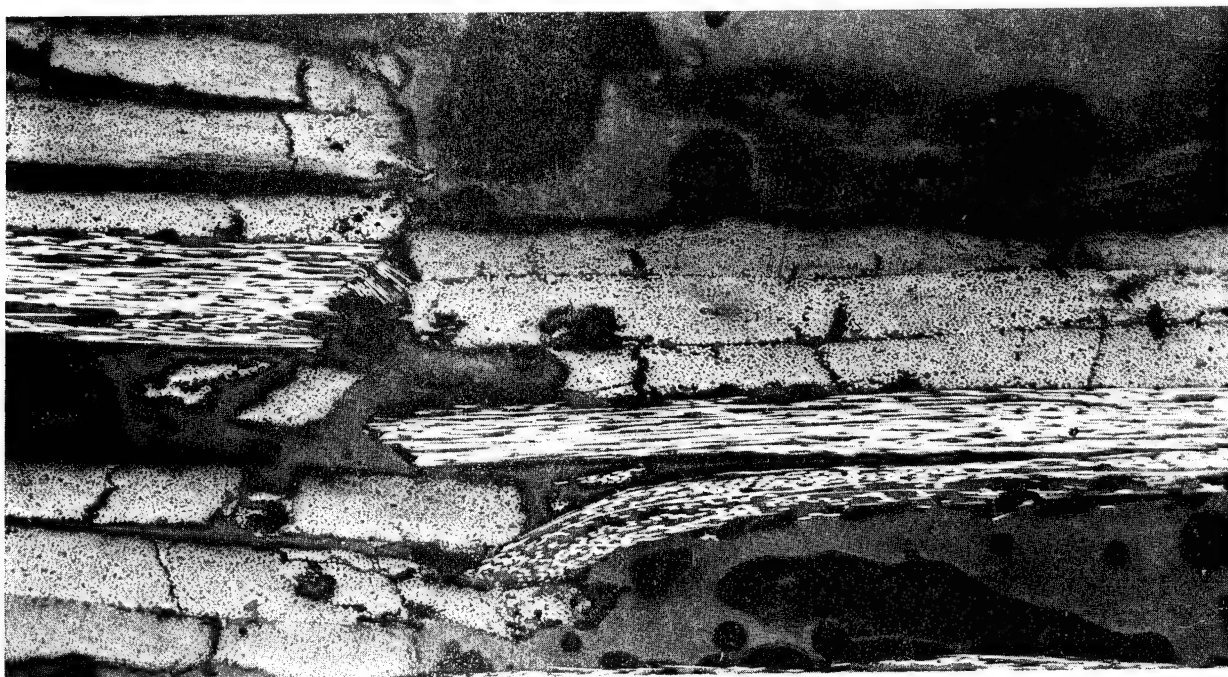


FIGURE 16. BP-907 3.39 JOULES (30 INCH POUNDS) GARDNER IMPACT

C



B



A

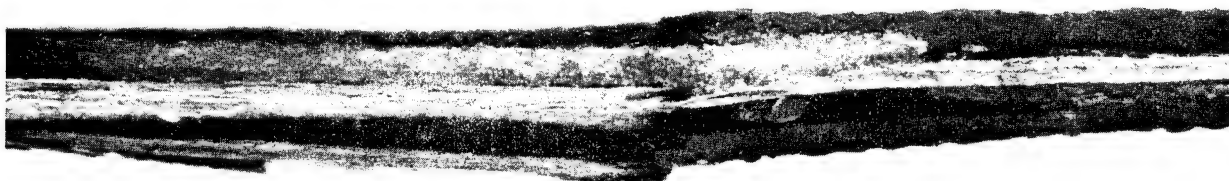
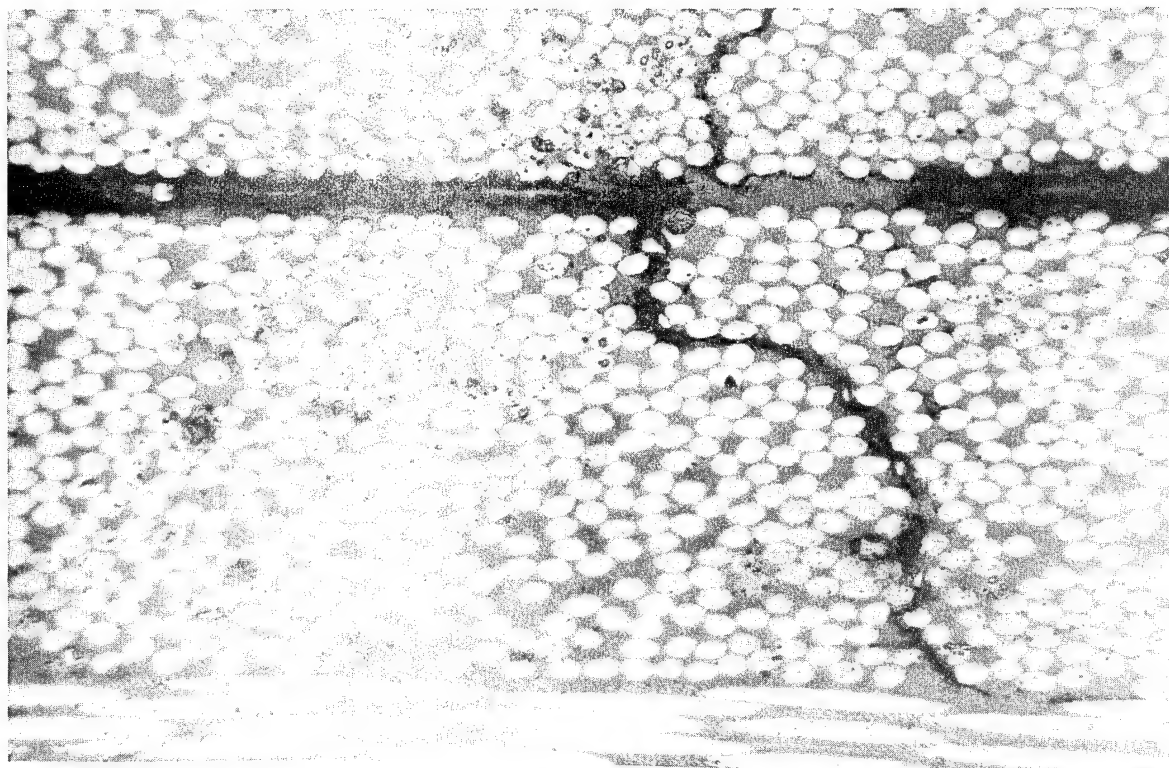
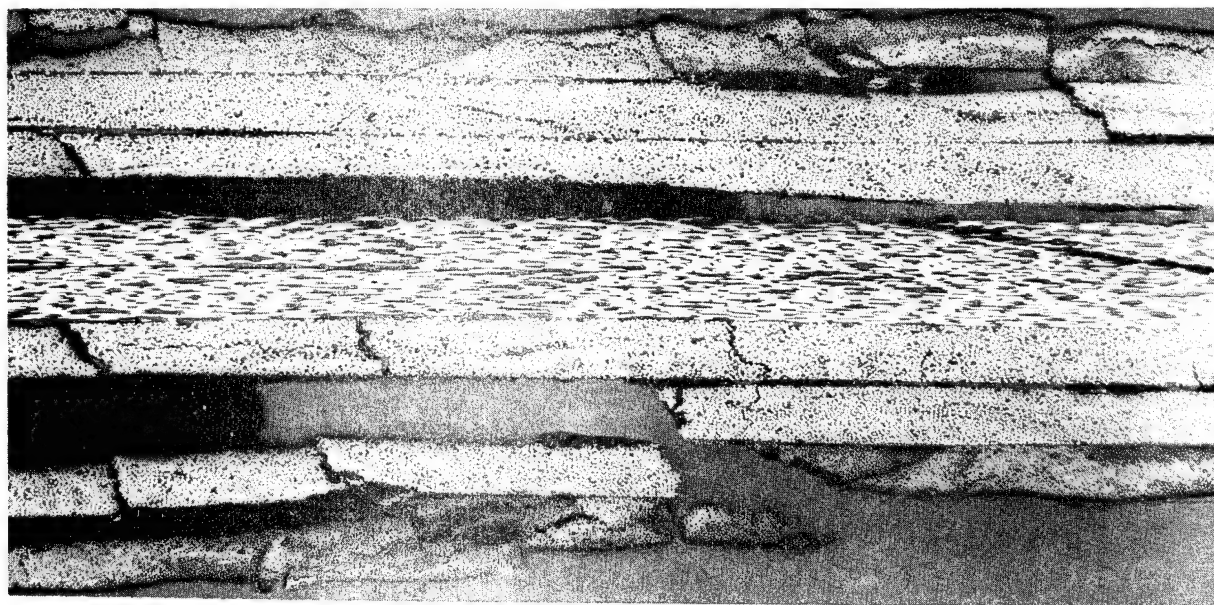


FIGURE 17. BP-907 9.04 JOULES (80 INCH POUNDS) GARDNER IMPACT

C



B

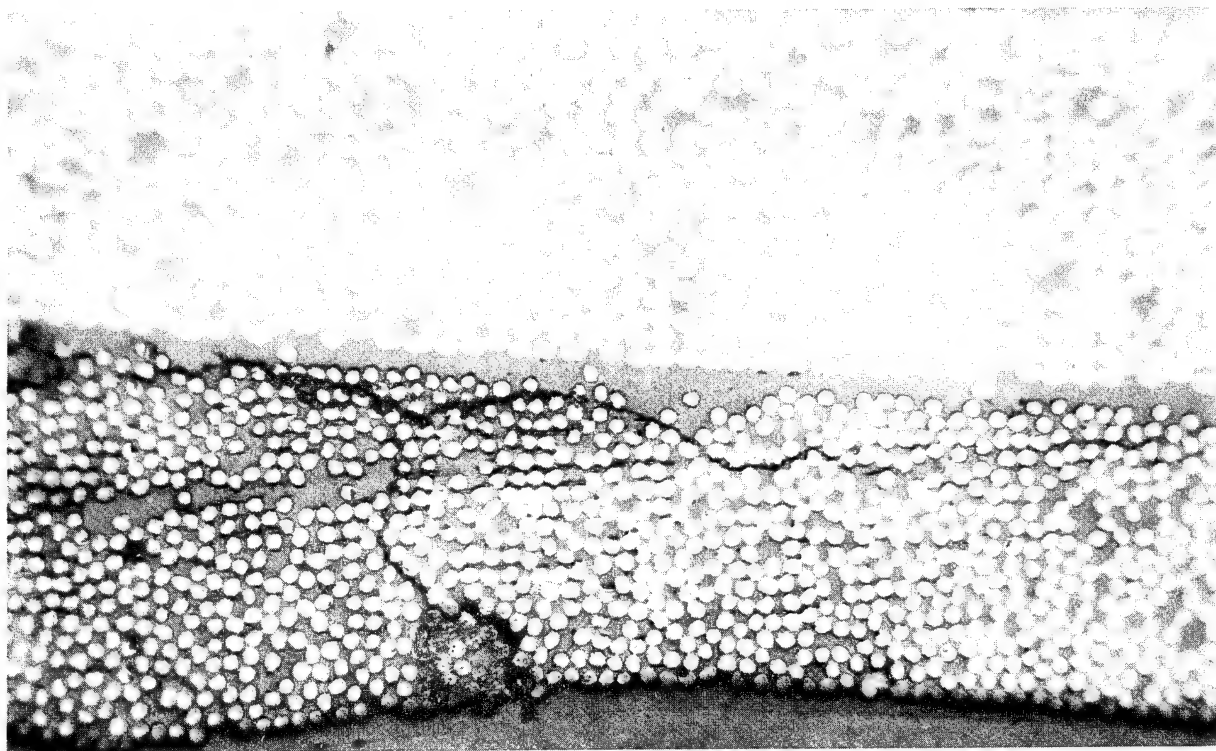


A

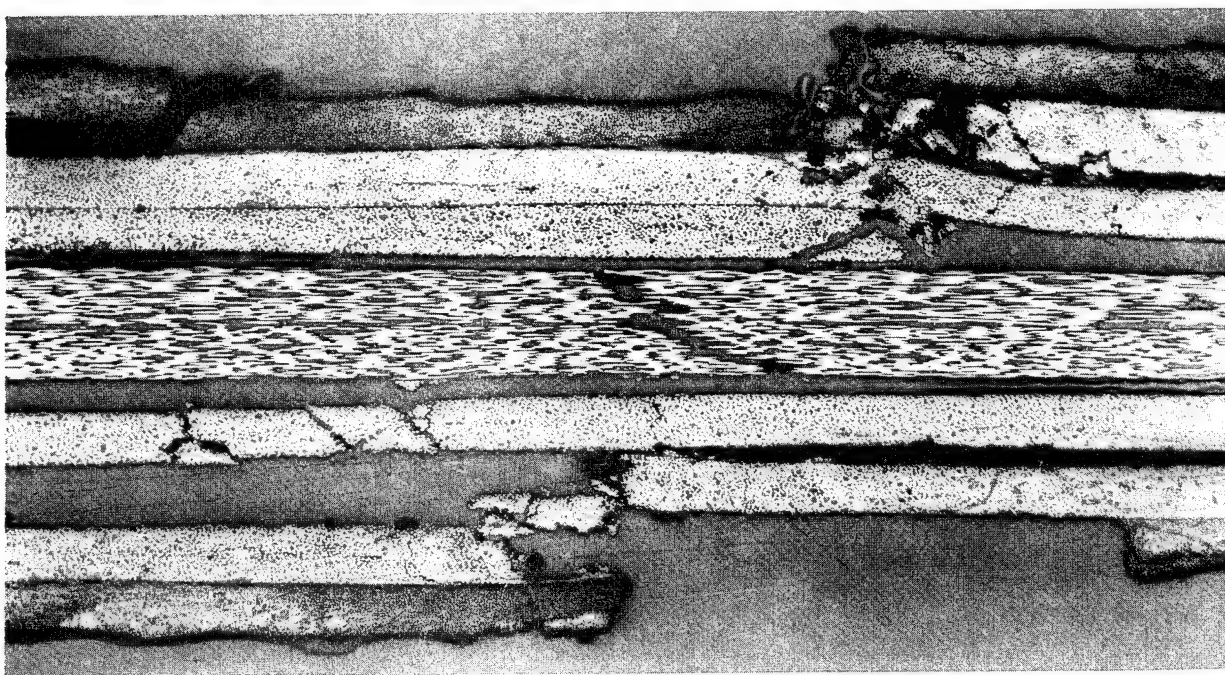


FIGURE 18. CIBA GEIGY #4 3.39 JOULES (30 INCH POUNDS) GARDNER IMPACT

C



B

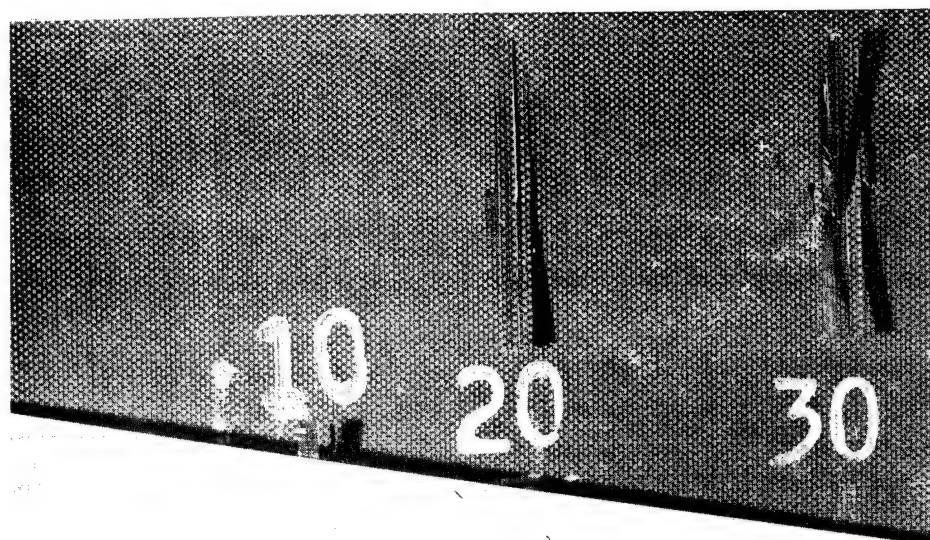


A



FIGURE 19. CIBA GEIGY #4 9.04 JOULES (80 INCH POUNDS) GARDNER IMPACT

Visible
Damage
Back side



NARMCO 5208/T300
REFERENCE

Visible
Damage
Front side

None

None

3.17 mm
(1/8 inch) hole +
broken fibers

a)

b)

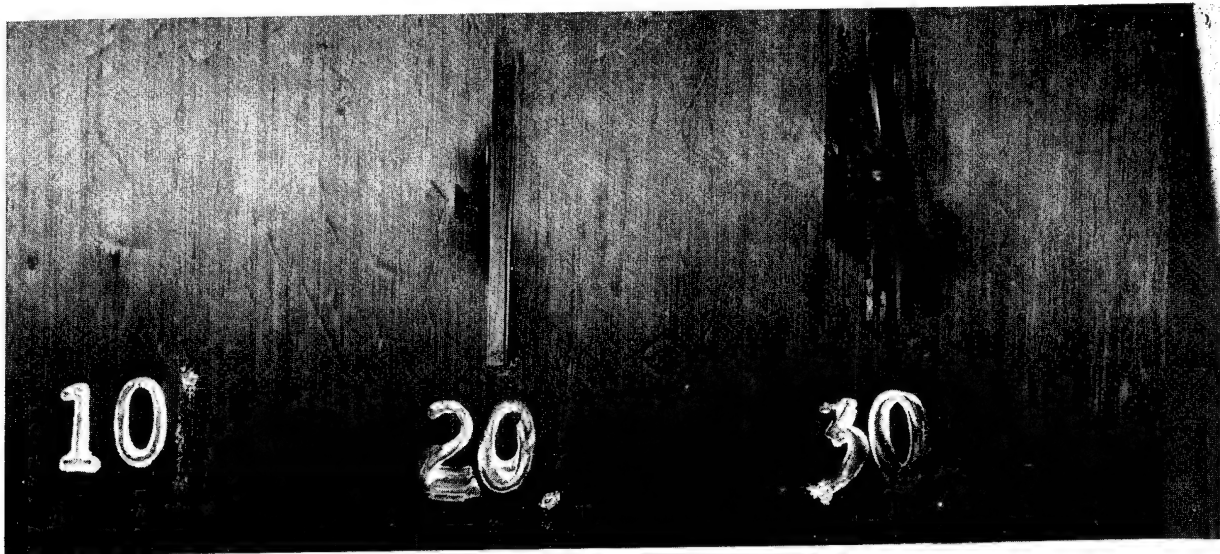
c)

Total Damage
by C-scan



FIGURE 20. COMPARISON OF VISUAL IMPACT DAMAGE VS. NDT INSPECTION FOR NARMCO 5208/T300 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



NARMCO 95995/T300

Visible
Damage
Front side

None

None

Broken Fibers

a)

b)

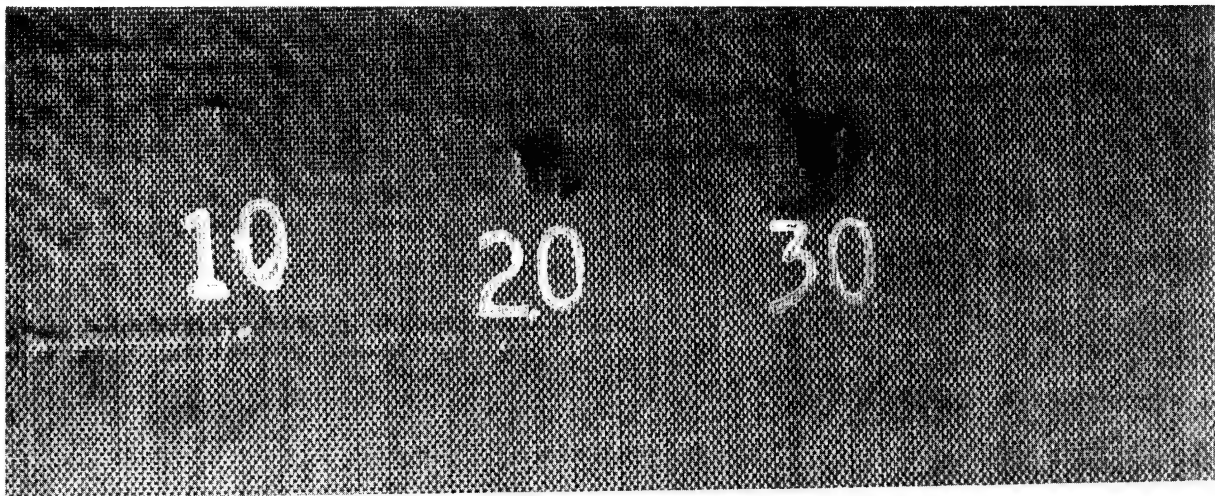
c)

Total Damage
by C-scan



FIGURE 21. COMPARISON OF VISUAL IMPACT DAMAGE VS. NDT INSPECTION FOR NARMCO 95995/T300 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



U.S. POLYMERIC TOUGH RESIN #1/T300

Visible
Damage
Front side

None

3.17 mm
(1/8 inch)
dent

6.35 mm
(1/4 inch) dent +
broken fibers

a)

b)

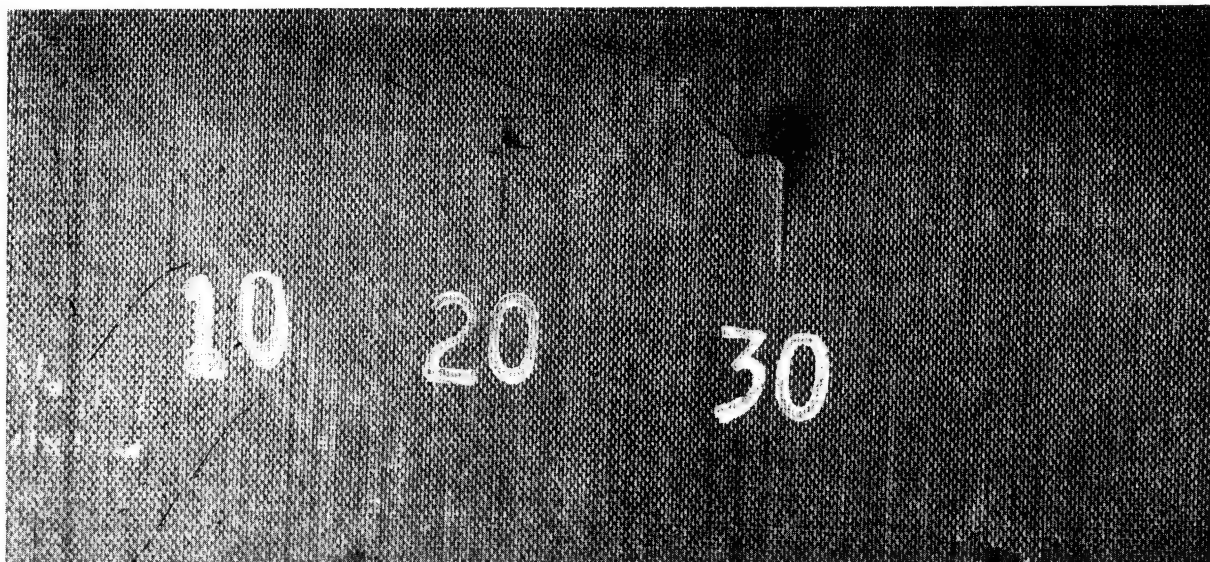
c)

Total Damage
by C-scan



FIGURE 22. COMPARISON OF VISUAL IMPACT DAMAGE VS. NDT INSPECTION FOR U.S. POLYMERIC TOUGH RESIN #1 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



AMERICAN CYANAMIDE BP-907/T300

Visible
Damage
Front side

None

a)

3.17 mm
(1/8 inch)
dent
b)

6.35 mm
(1/4 inch) dent +
broken fibers
c)

Total Damage
by C-scan.

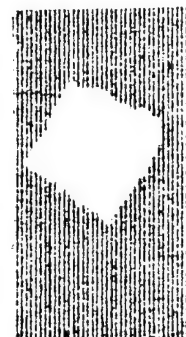
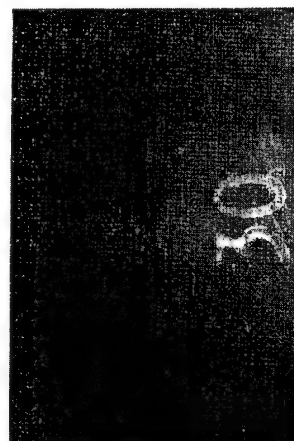
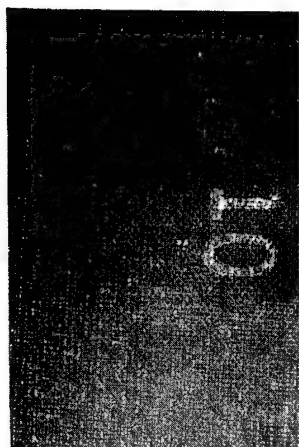


FIGURE 23. COMPARISON OF VISUAL IMPACT DAMAGE VS NDT INSPECTION FOR AMERICAN CYANAMID BP-907 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH-POUNDS), b. 2.26 JOULES (20 INCH-POUNDS) AND c. 3.39 JOULES (30 INCH-POUNDS)

Visible
Damage
Back side



Visible
Damage
Front side

None

(a)

None

(b)

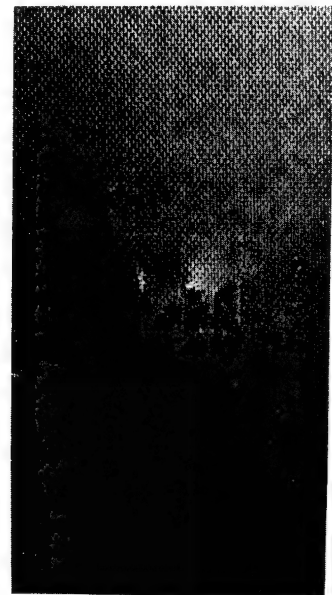
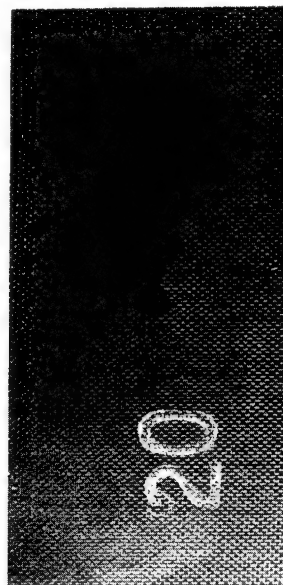
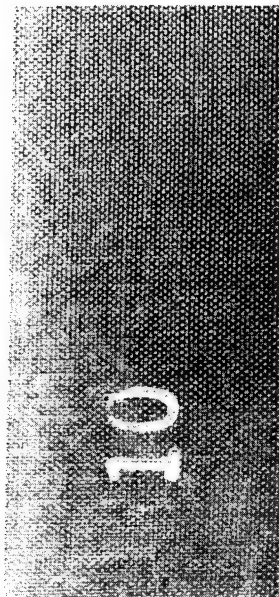
5.1 mm
(.2 inch) dent
some broken
fibers
(c)

Total Damage
by C-scan



FIGURE 24. COMPARISON OF VISUAL IMPACT DAMAGE VS NDT INSPECTION FOR CIBA GEIGY #4 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH POUNDS), b. 2.26 JOULES (20 INCH POUNDS) AND c. 3.39 JOULES (30 INCH POUNDS)

Visible
Damage
Back side



Visible
Damage
Front side

None

None

6.35 mm
(1/4 inch)
dent

(a)

(b)

(c)

Total Damage
by C-scan



FIGURE 25. COMPARISON OF VISUAL IMPACT DAMAGE VS NDT INSPECTION FOR FIBERDUX 920 FOR 3.17 cm (1.25 INCH) SUPPORT AT a. 1.13 JOULES (10 INCH POUND), b. 2.26 JOULES (20 INCH POUND) AND c. 3.39 JOULES (30 INCH POUND)




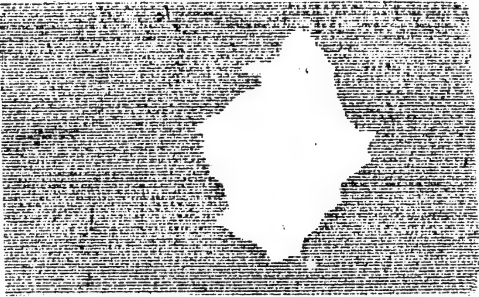
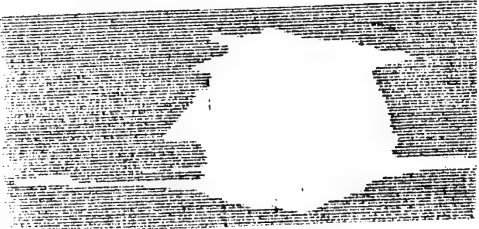
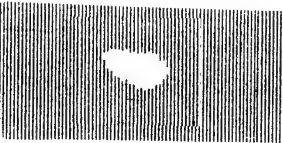
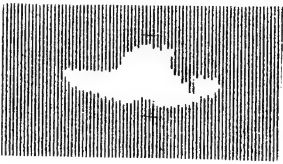
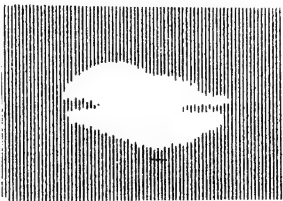
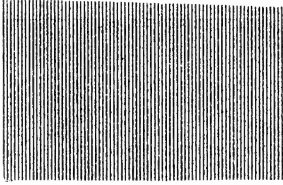
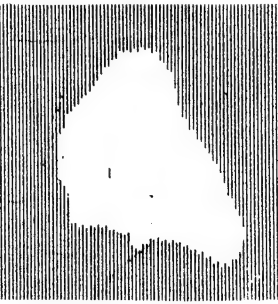





Joules Impact - (inch - pound)	1.13 (10) Round	2.26 (20) Round	3.39 (30) Round	6.78 (50) Flat	9.04 (80) Flat
Narmco 5208					
C-scan damage area (in ²) cm ²	(.26) 1.69	(.56) 3.64	(.82) 5.33	(1.56) 10.14	(2.22) 14.43
Ciba Geigy #4					
C-scan damage area (in ²) cm ²	(.10) .65	(.32) 2.08	(.59) 3.83	(0) 0	(1.60) 10.40
American Cyanamide BP 907					
C-scan damage area (in ²) cm ²	(.04) .26	(.16) 1.04	(.30) 1.95	(.76) 4.94	(.86) 5.59

FIGURE 26. THIN LAMINATE GARDNER IMPACT (0°, ±45°, 90°)_s

2.5.1.2 Rheometric Impact Specimens

The criteria for evaluation of the Rheometric impact results are:

- a. Load at apparent yield
- b. Deflection at apparent yield
- c. Area under the stress/strain curve to yield
- d. Total area under the stress/strain curve at total penetration

The Rheometric Constant Speed Penetration Impact machine, located at NASA-Langley Field, was used for these tests. The load vs deflection curve was plotted by the machine as the impact head penetrated the specimen at a constant velocity of 76.2 meters per minute (3000 inches per minute). The operator selected the yield point and the total penetration point to allow the machine to calculate the areas under the stress/strain curves at these points.

The load and deflection at the operator selected yield point for all toughened material systems were, as expected, greater than the 5208 yield point. (Table 4 and Appendix 3.)

A study of Figure 27 data shows the superior laminate impact resistance properties of toughened resin matrix systems, with BP-907 as a typical example, compared to the standard Narmco 5208 material, by both Rheometric and Gardner impact tests.

The energy absorbed at "yield" for the Gardner Impact, or area under the stress-strain curve to yield, is greater for the BP-907 (1.22 Joules) than for the Narmco 5208 (1.06 Joules) material. At total penetration, the energy absorbed is also greater for the BP-907 (7.31 Joules) than the Narmco 5208 (4.63 Joules) material.

The Gardner impact data also supports the conclusion that the BP-907 graphite/epoxy laminate has superior damage tolerance or impact resistance than Narmco 5208 laminates. The area of damage, shown by C-scan examination, of Gardner impact damaged panels was less for BP-907 (0.26 cm²) than for Narmco 5208 (1.69 cm²) material at low 1.13 joules (10 inch pounds) impact. At high load impact of 9.04 joules (80 inch pounds), the BP-907 area of damage, 5.59 cm² is much less than the 14.43 cm² damage for the Narmco 5208 material.

At total penetration, the Rheometric total "energy absorbed" values for all toughened materials recorded in Table 4 were, as expected from the Gardner Impact Tests, superior to the Narmco 5208. An additional example of this correlation is shown in Figure 28 for Narmco 5208 and Ciba Geigy #4 materials. Note that the higher Rheometric energy absorbed value by Ciba Geigy #4 indicated improved impact resistance. At the same time smaller area damage of the Gardner Impact Test, shown by C-scan also indicates improved impact strength for the Ciba Geigy material.

136kg (300 lbs)

90.6 (200)

Load - 136 kg (300 lbs) Total

-45-



5.59 cm²

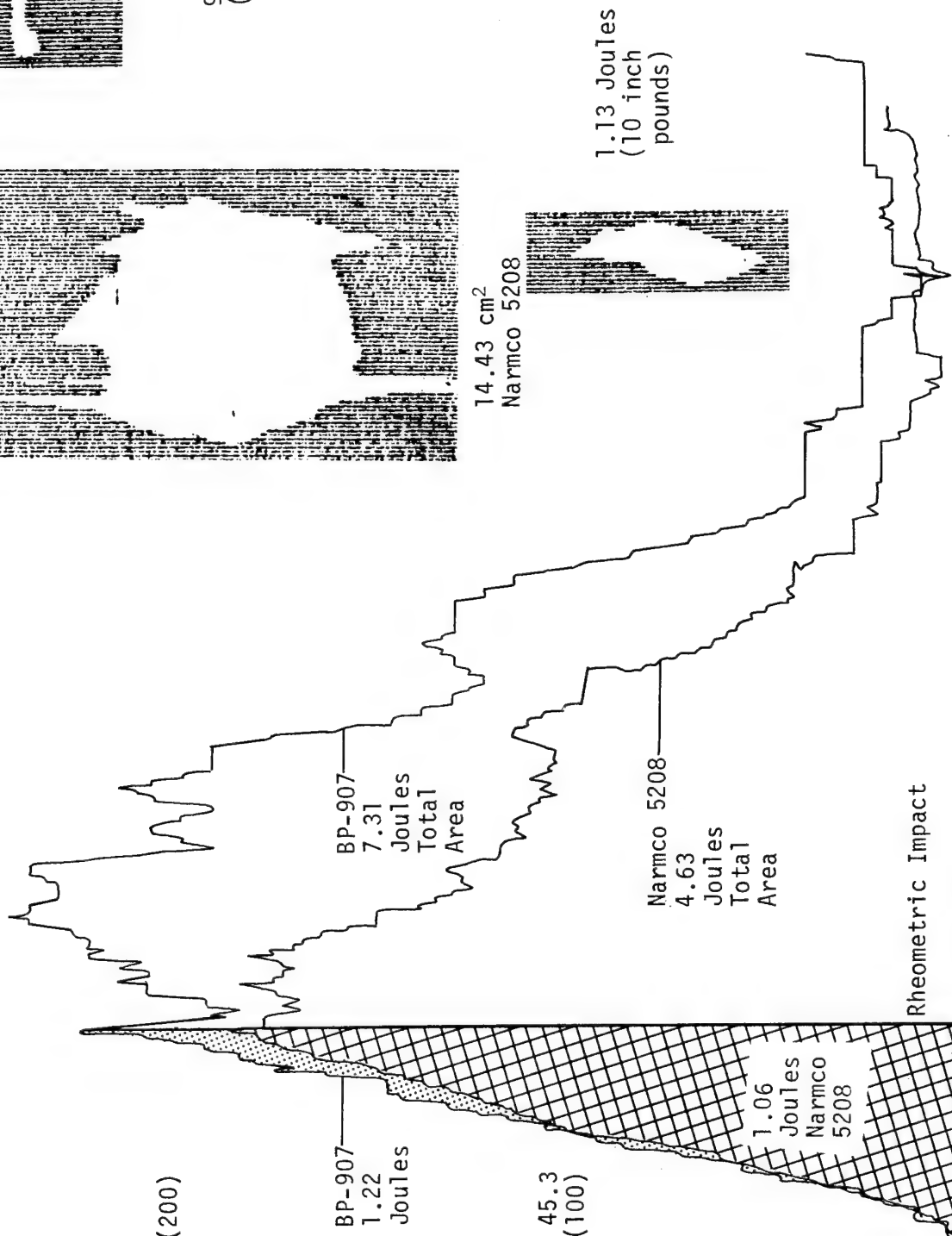
9.04 Joules
(80 inchpounds)

BP-907



14.43 cm²
Narmco 5208

1.13 Joules
(10 inch
pounds)



Rheometric Impact

Deflection (inches)	BP-907 (Joules)	Narmco 5208 (Joules)
2.5	1.22	1.06
5.1	7.31	4.63
7.6	9.04	5.79
10.2	9.04	6.75
12.7	9.04	7.81
15.2	9.04	8.87
17.8	9.04	9.93

Total Deflection - Millimeters (inches)

FIGURE 27. BP-907 VS NARMCO 5208 FOR RHEOMETRIC IMPACT AND GARDNER IMPACT AREA OF DAMAGE

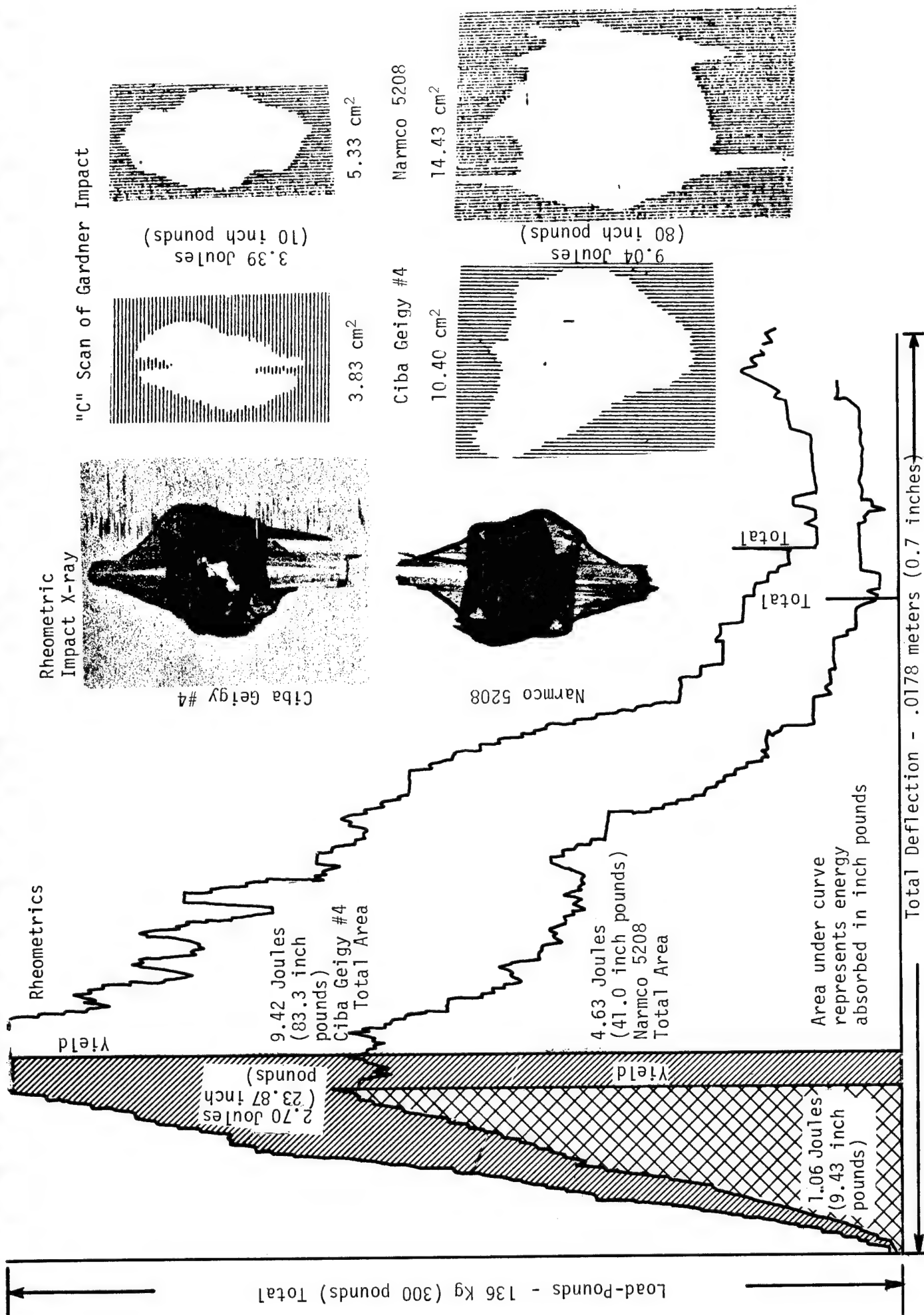


FIGURE 28. CIBA GEIGY #4 VS NARMCO 5208 FOR RHEOMETRIC IMPACT AND GARDNER IMPACT AREA OF DAMAGE

An interesting observation of the Rheometric impact penetration specimens is that the impact penetration hole was closed with broken fibers for the Narmco 5208 specimens but every toughened material contained a visible hole, with broken fiber edges, where the impact plunger penetrated. The X-rays of the impacted specimens in Figure 28 show this characteristic.

The use of the Rheometric Impact Tester has been limited to a few specimens for this program and the means of selecting the critical yield and total failure points are still in development. The equipment, with further testing and understanding, should become a valuable tool for the study of low velocity impact phenomenon.

2.5.1.3 Potential Rheometric Impact Tester Use

The Rheometric Impact tester can reduce the data in the plastic deformation area of the stress strain curve (before yield) to a kilograms per meter (pounds per inch) slope - a measurement of modulus of elasticity. If the machine were adjusted to a slow velocity (impact) and stopped before yield or internal damage occurred, the data might prove useful as a Quality Control measure. The proper slope or modulus of elasticity function from reduced data would indicate certain qualities of the part such as:

1. Proper fiber pattern
2. Proper thickness
3. Proper processing cure cycle.

The equipment seems to have the potential to offer a quick low cost NDT procedure for production Quality Control evaluation.

2.5.2 Correlation of Resin Properties to Laminate Impact Damage Area

Neat resin tensile ultimate, modulus and % elongation were obtained on as many of the resin systems as possible. These resin properties were compared to the area of damage at various levels of impact damage (Gardner impact) for laminates made for each of the resin systems and Thornel 300 fiber reinforcement. The data was plotted and the curves were obtained from a general least square best line of fit program using an HP 9825A calculator plotter.

2.5.2.1 Neat Resin Tensile Strength Vs Impact Resistance

The resin tensile strength is not an important resin variable for developing laminate impact resistance as shown in Figure 29. Toughened resins with both higher and lower tensile strength than Narmco 5208 resin produced higher impact resistant laminates.

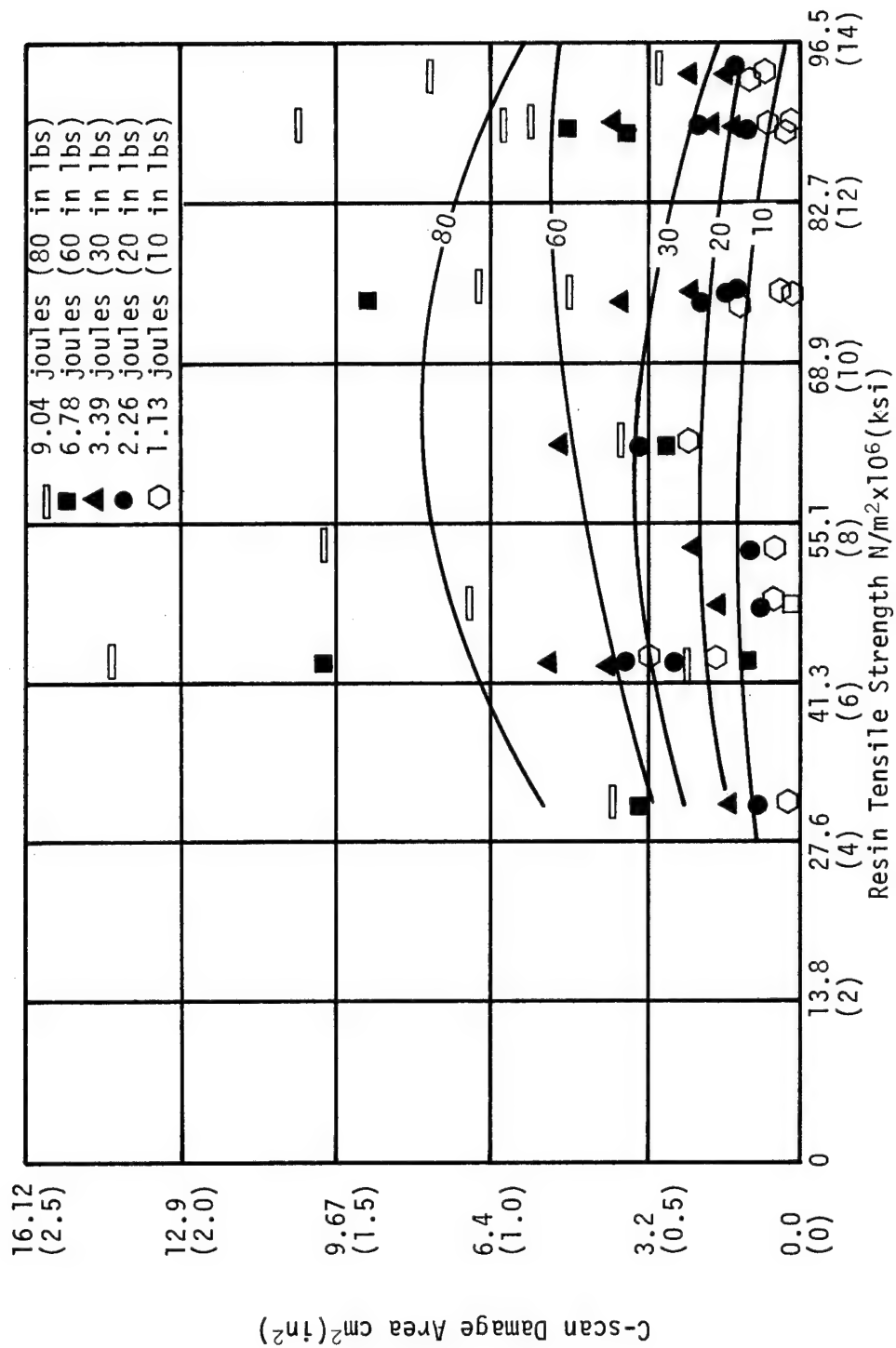


FIGURE 29. NEAT RESIN TENSILE STRENGTH VS IMPACT DAMAGE AREA

2.5.2.2 Neat Resin Tensile Modulus Vs Impact Resistance

The resin tensile modulus is an important variable in the development of laminate impact resistance as shown in Figure 30. As the resin tensile modulus increases, the extent of the impact damage area increases and therefore the impact damage tolerance decreases. However, once the resin tensile modulus drops below $3.1 \times 10^9 \text{ N/m}^2$ (450,000 psi) there is no significant improvement in impact resistance.

2.5.2.3 Neat Resin Tensile % Elongation Vs Impact

It was observed that all of the tough resin systems evaluated had an elongation to failure greater than 5208. Figure 31 shows how the area of damage for five levels of impact as recorded on the C-scan varied with the % tensile elongation of the resin. There was a noticeable improvement in impact resistance with increased tensile elongation of the resin. However, once the % elongation reaches 5 or 6% there was only a small gain in impact resistance. Resin elongation appears to be a major variable in controlling laminate properties.

2.5.3 Correlation of Resin Properties and Laminate Mechanical Properties

Mechanical property tests (tensile, compression, interlaminar shear and flexural strength) were conducted on laminate panels made with all toughened resin systems and compared to the baseline Narmco 5208. The purpose of the work was to improve impact characteristics with a minimum or no loss of laminate mechanical properties.

2.5.3.1 Tensile Strength of Resin Vs Laminate Mechanical Properties

The neat resin tensile strength does not have significant effect on the tensile strength of the cured laminate as shown in Figure 32. There is minimal effect on laminate compression and flexural strength until the resin tensile strength drops below $5.5 \times 10^7 \text{ N/M}^2$ (8000 psi). Interlaminar shear strength appears to drop as resin tensile strength falls below $4.8 \times 10^7 \text{ N/M}^2$ (7000 psi) and raises above $9 \times 10^7 \text{ N/M}^2$ (13,000 psi).

2.5.3.2 Tensile Modulus of Resin vs Laminate Mechanical Properties

The neat resin tensile modulus appears to be more important than resin tensile strength in controlling laminate mechanical properties. There is a rapid decline in flexural, interlaminar shear and compression strength in laminates when the resin tensile modulus falls much below $344 \times 10^7 \text{ N/M}^2$ (500,000 psi) as shown in Figure 33. The laminate tensile strength is less affected with change in resin tensile modulus, but does show a gradual reduction in laminate tensile properties as the resin modulus declines.

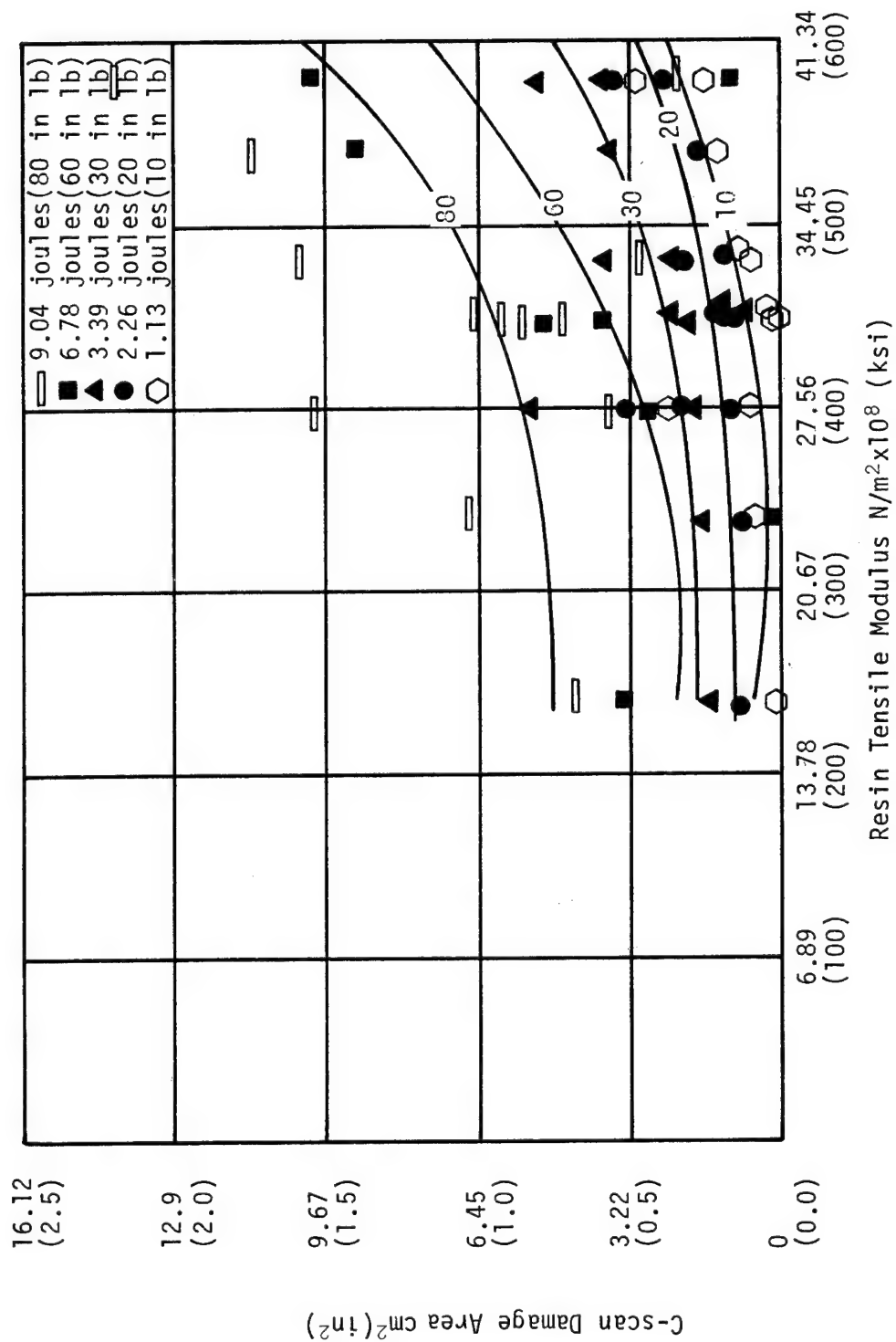


FIGURE 30. NEAT RESIN TENSILE MODULUS VS IMPACT DAMAGE AREA

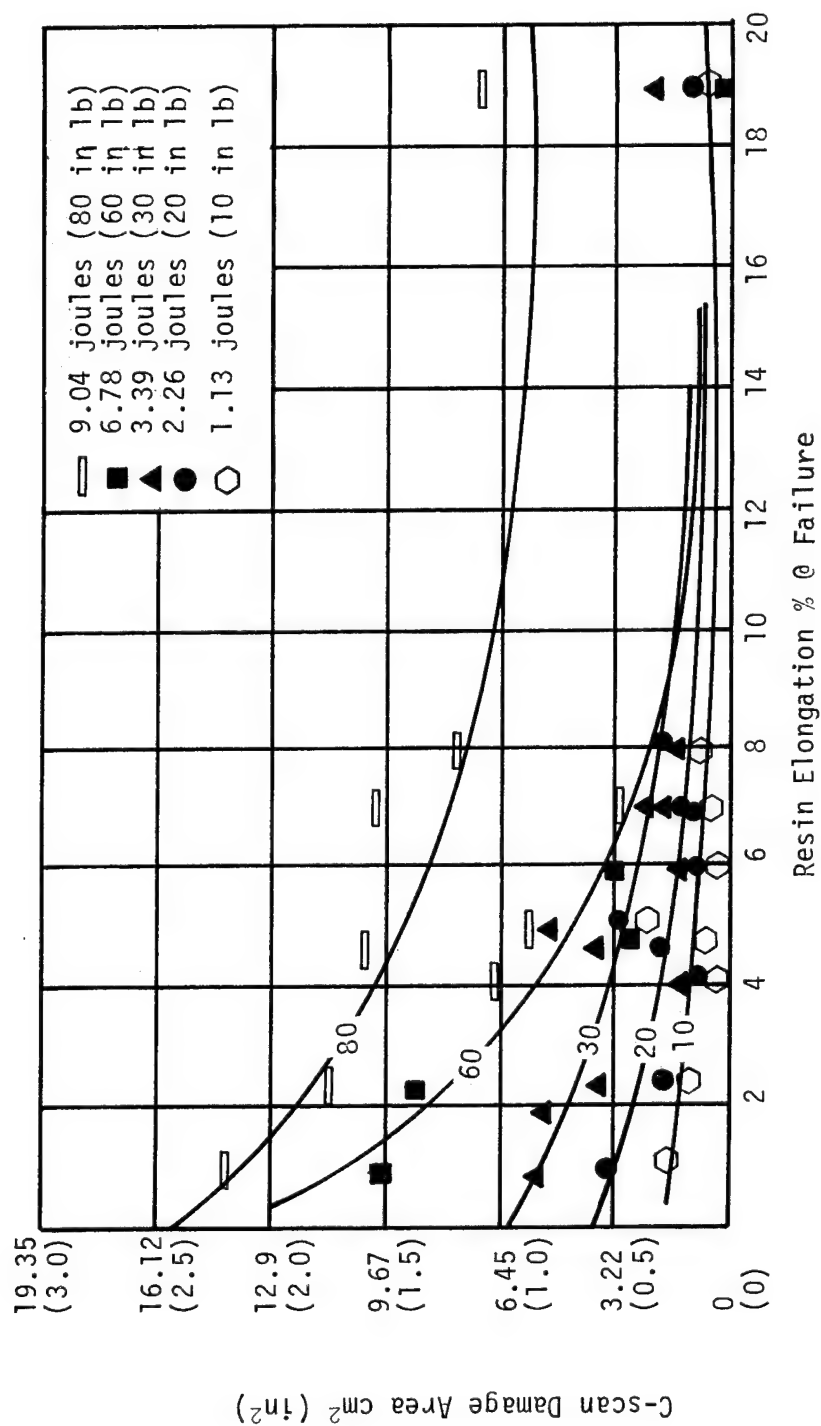


FIGURE 31. NEAT RESIN % ELONGATION AT FAILURE VS. IMPACT DAMAGE AREA

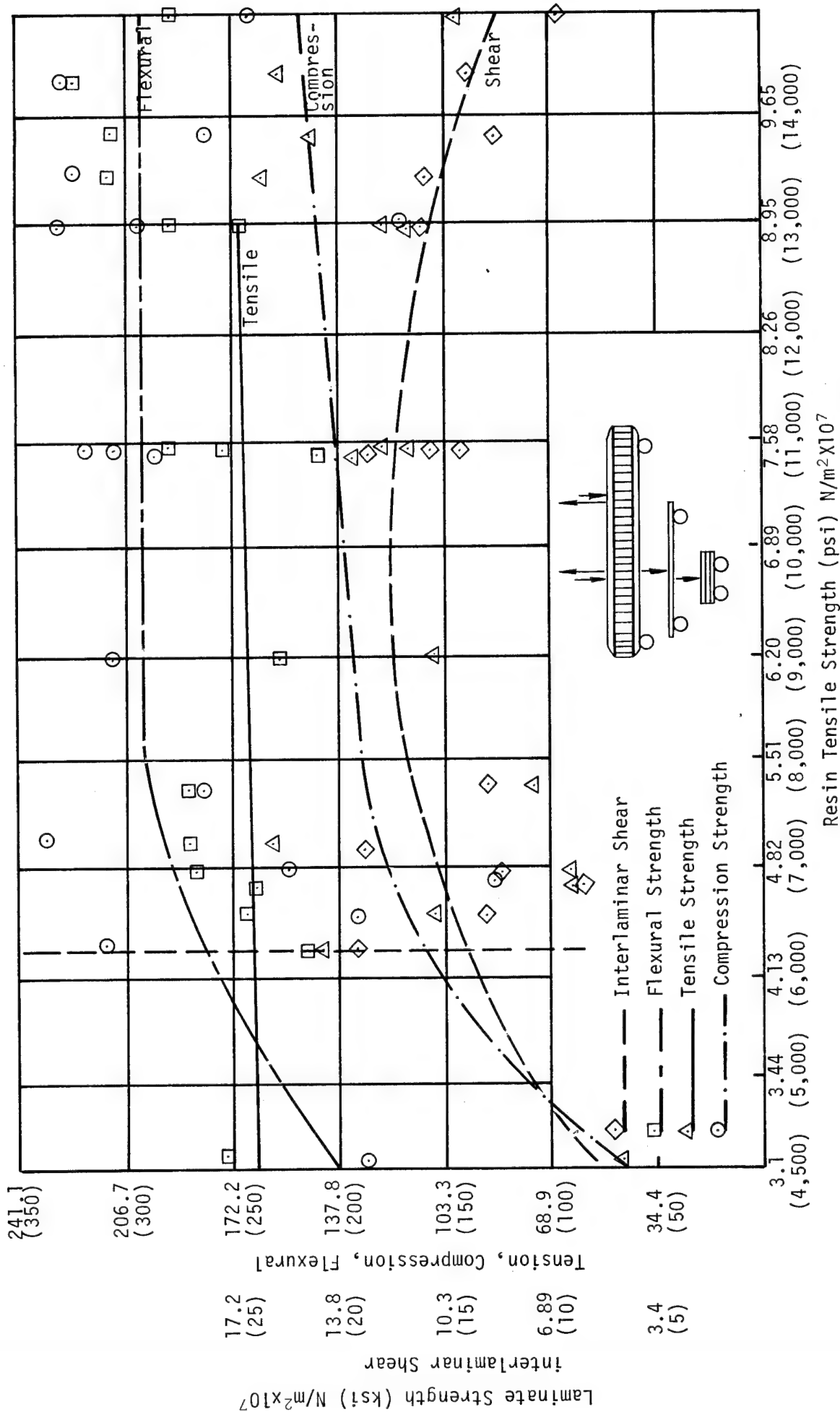


FIGURE 32. RESIN TENSILE STRENGTH VS LAMINATE MECHANICAL PROPERTIES

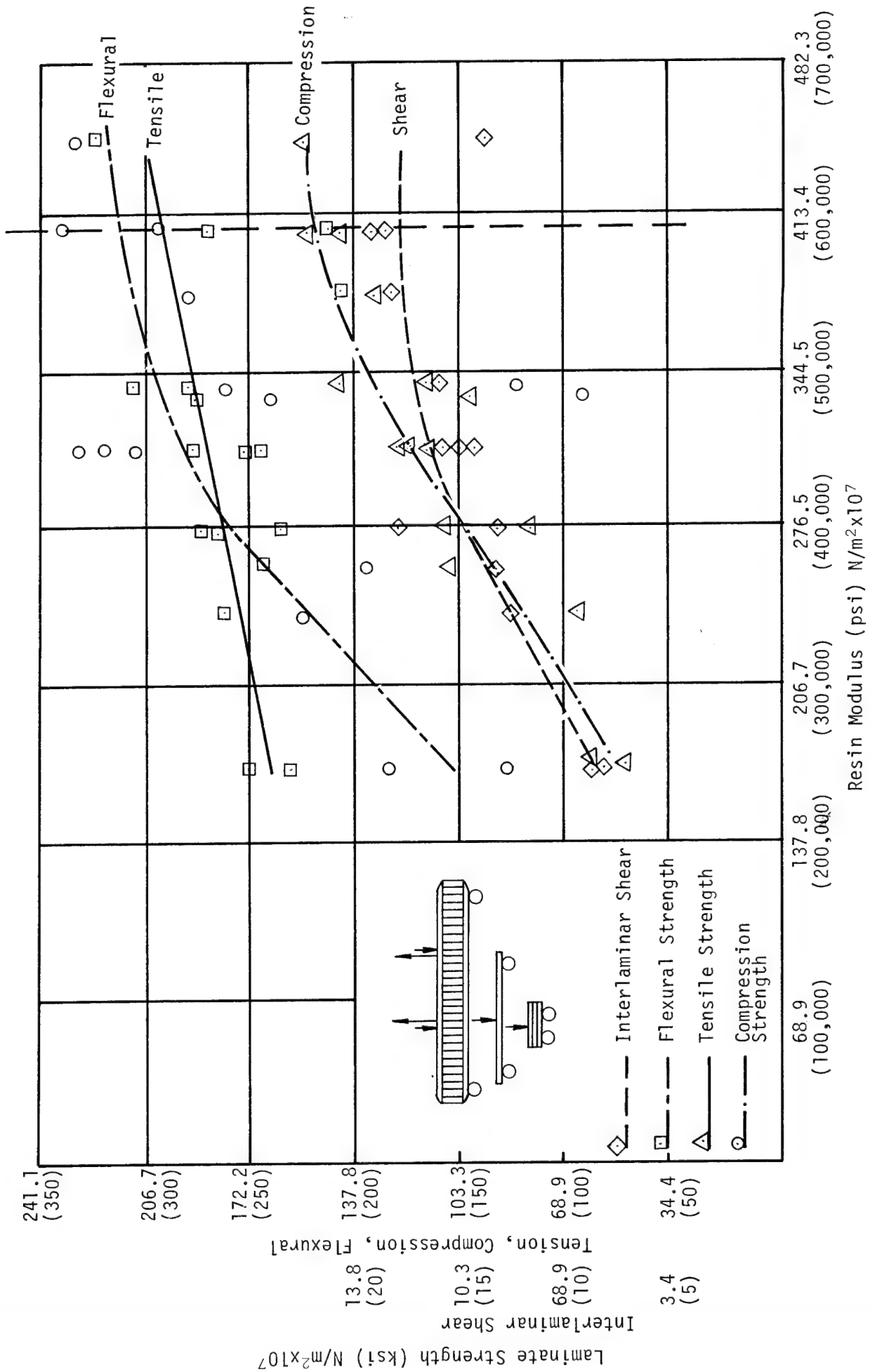


FIGURE 33. RESIN TENSILE MODULUS VS LAMINATE MECHANICAL PROPERTIES

2.5.3.3 Tensile Elongation of Resin Vs Laminate Mechanical Properties

The resin tensile elongation has a varied effect on laminate properties as shown in Figure 34. The flexural strength remains nearly constant until the resin tensile elongation increases above 6%. Above this level there was a rapid loss of flexural strength. Laminate tensile strength increased with resin tensile elongation until about 5% elongation and remained unaffected at higher resin elongation. Laminate compression and interlaminar shear strength gradually reduced as the resin elongation increased.

2.5.4 Threshold of Impact Damage

Figures 35, 36 and 37 show cross sectional photomicrographs at 20x magnification for composite plates constructed using Narmco 5208, BP 907, Ciba Geigy #4 and Fiberdux 920 resins and impacted by the Gardner Tester at several levels near the threshold of damage. (The arrow shows the point of impact.) C-scans of the same area are shown. The three toughened systems exhibit significantly less damage at all levels compared to 5208 as previously discussed. The majority of the damage occurred on the side opposite the impact.

The 5208 laminate was damaged at very low impact levels. Cracks and delaminations are present at .45 joules (4 inch pounds) (see Figure 37), well below the damage threshold of approximately 1.13 joules (10 inch pounds) for the other three materials. The 5208 laminate had one interesting failure characteristic; the resin cracks through the plies all point toward the point of impact. Thick laminates exhibit the same type of failure at comparative low impact levels. the toughened materials did not show this type of failure. In general, they failed by delamination with the exception of Fiberdux 920, which randomly shattered at 2.26 joules (20 inch pounds).

2.6 VALIDITY OF LAMINATE MECHANICAL AND NEAT RESIN DATA

The results of this program must be considered only as a starting guideline for desirable neat resin properties. Each material system evaluated, was based on a single batch of material. The cure cycles used to cure the test panels were carefully monitored to assure exact processing as specified by the material supplier. However, many of these development systems have not had even a start at a process optimization study. Note that even in the case of Narmco 5208/T-300, that a modified slow curing cycle (see Figure 38) produced a panel with higher mechanical properties and greater resistance to impact than the panel with the standard cure cycle. (See Figure 39). Thus, it could be expected that altering the curing cycles of other materials could also revise their properties. Note that in Figure 39 that 1.13 (10), 2.26 (20) and 3.39 joules (30 inch pounds) Gardner Impact Tests were conducted using a 15.9 mm (5/8 inch) impact head. The 6.78 (60) and 9.03 joules (80 inch pound) panel impact tests used a 5/8" flat impact head. The flat head spread the load over a greater area than the round head and caused the threshold of

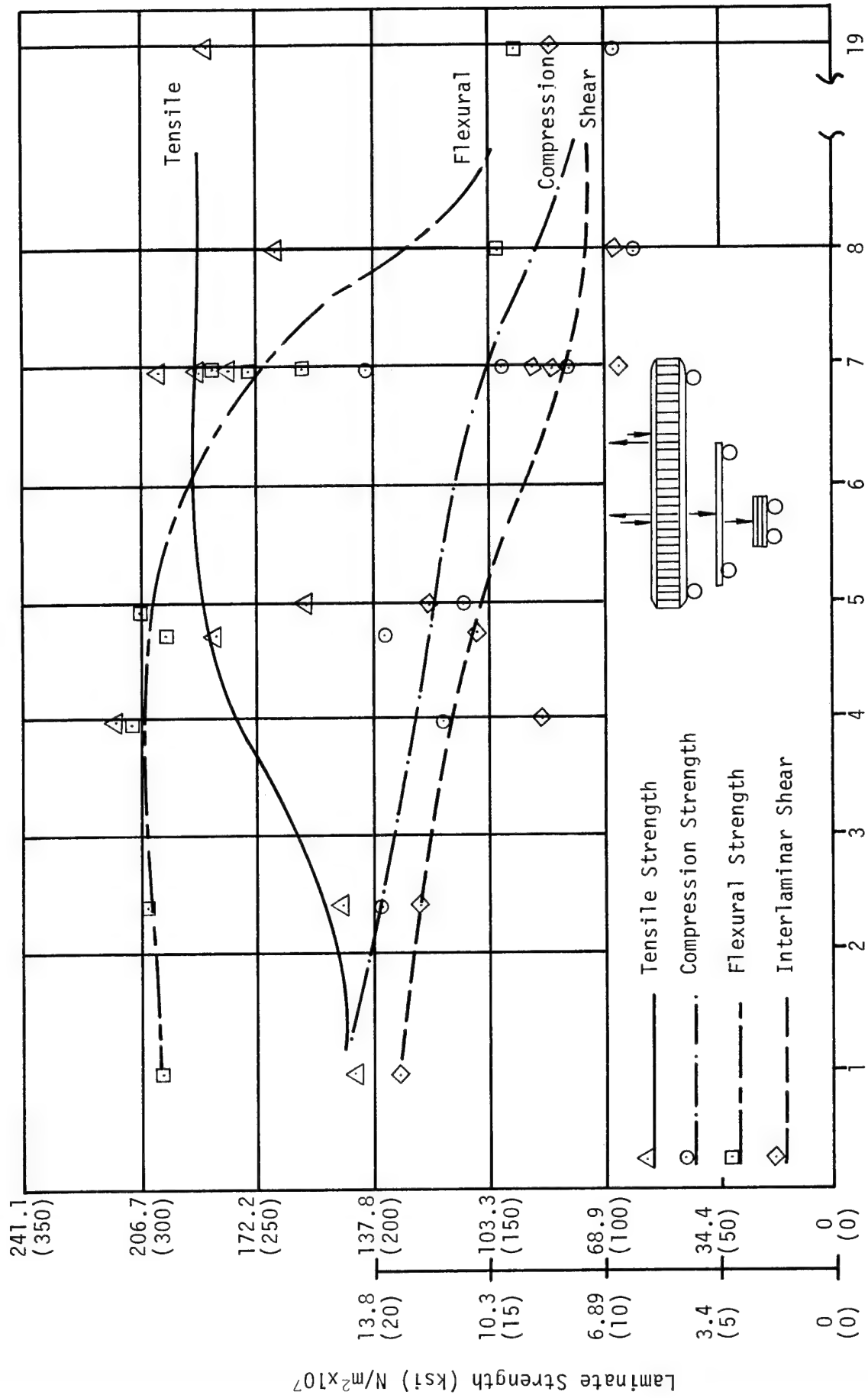
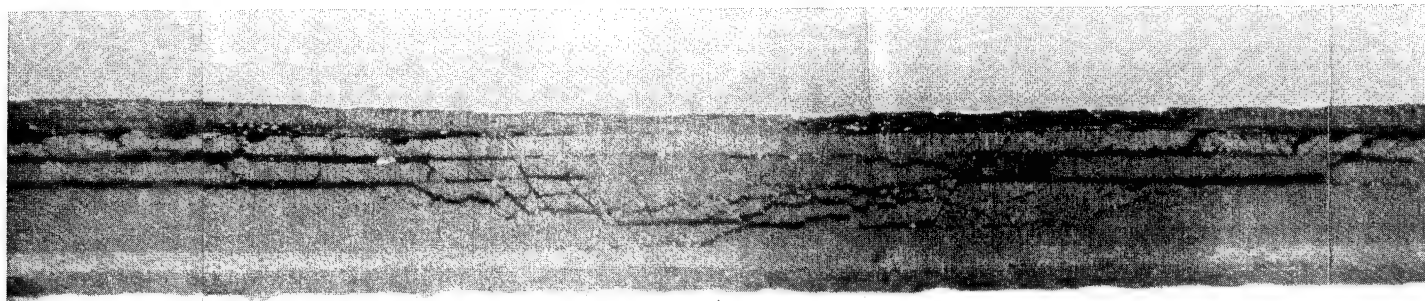
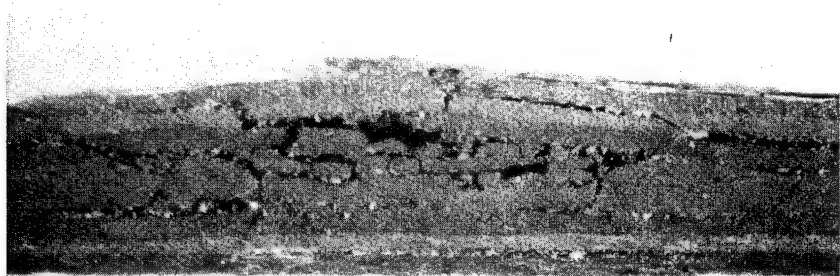


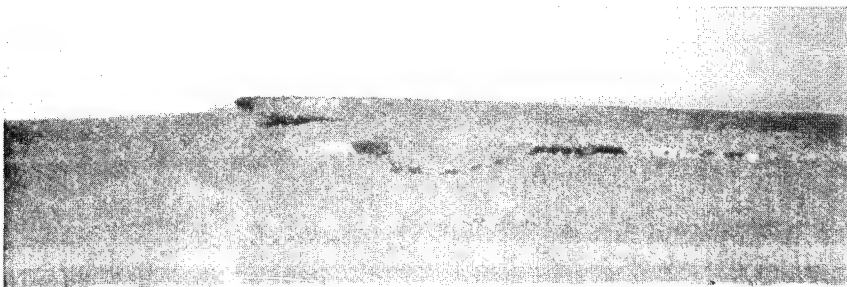
FIGURE 34. RESIN TENSILE ELONGATION VS LAMINATE MECHANICAL PROPERTIES



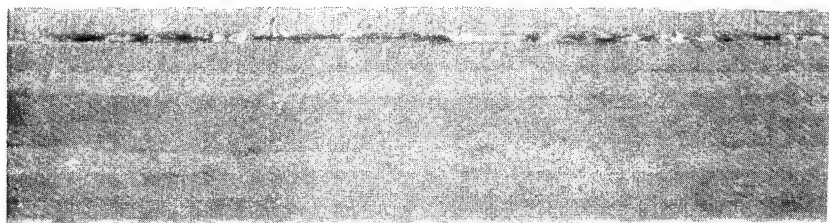
a. Narmco 5208/T-300



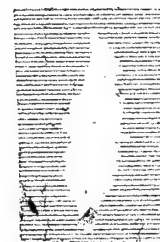
b. Fiberdux 920



c. BP 907



d. Ciba Geigy #4



a



b

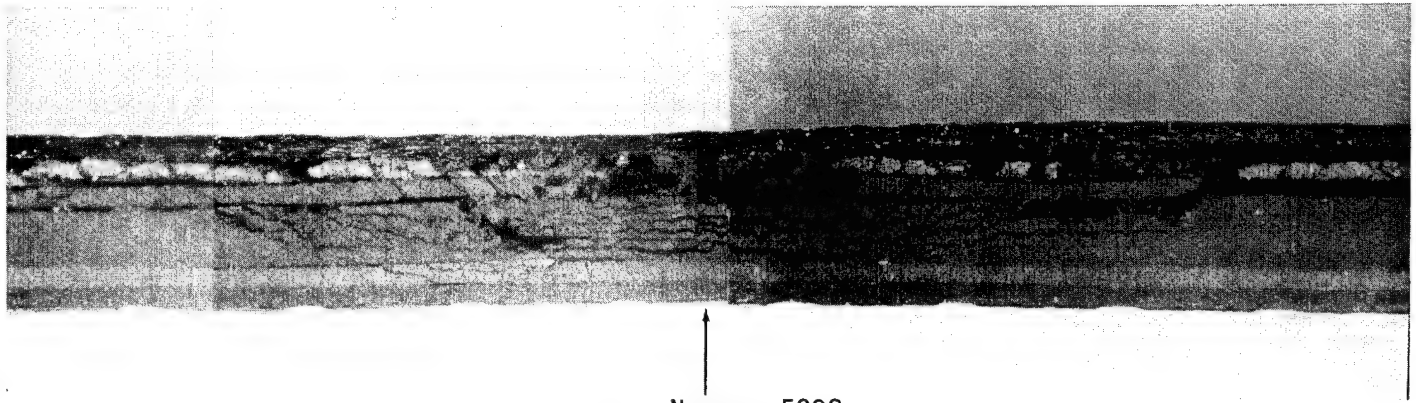


c

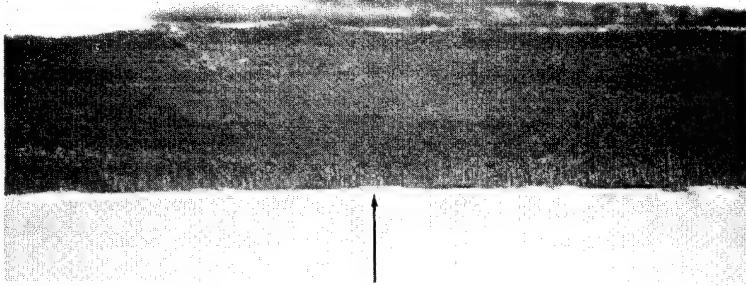


d

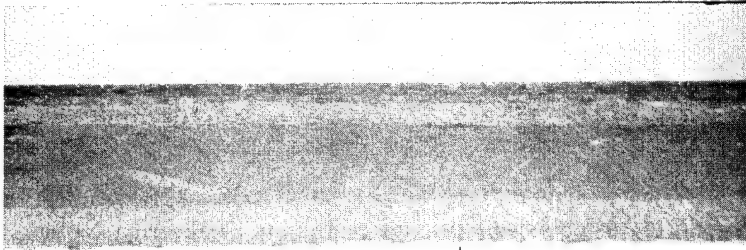
FIGURE 35. PHOTOMACROGRAPHS AT 20x & C-SCAN OF 2.26 JOULES (20 INCH POUNDS) IMPACT



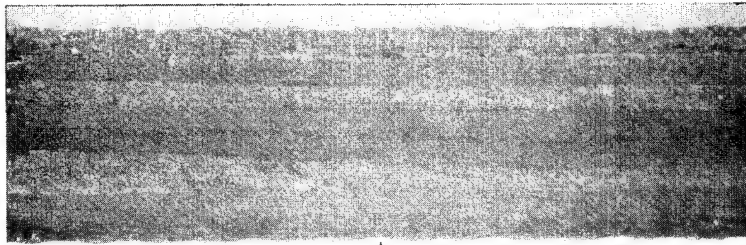
a. Narmco 5208



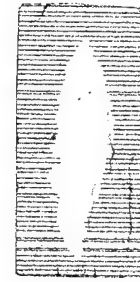
b. Fiberdux 920



c. BP-907



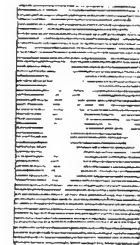
d. Ciba Geigy #4



a



b



c



d

FIGURE 36. PHOTOMACROGRAPHS AT 20x & C-SCAN OF 1.13 JOULES (10 INCH POUNDS) IMPACT

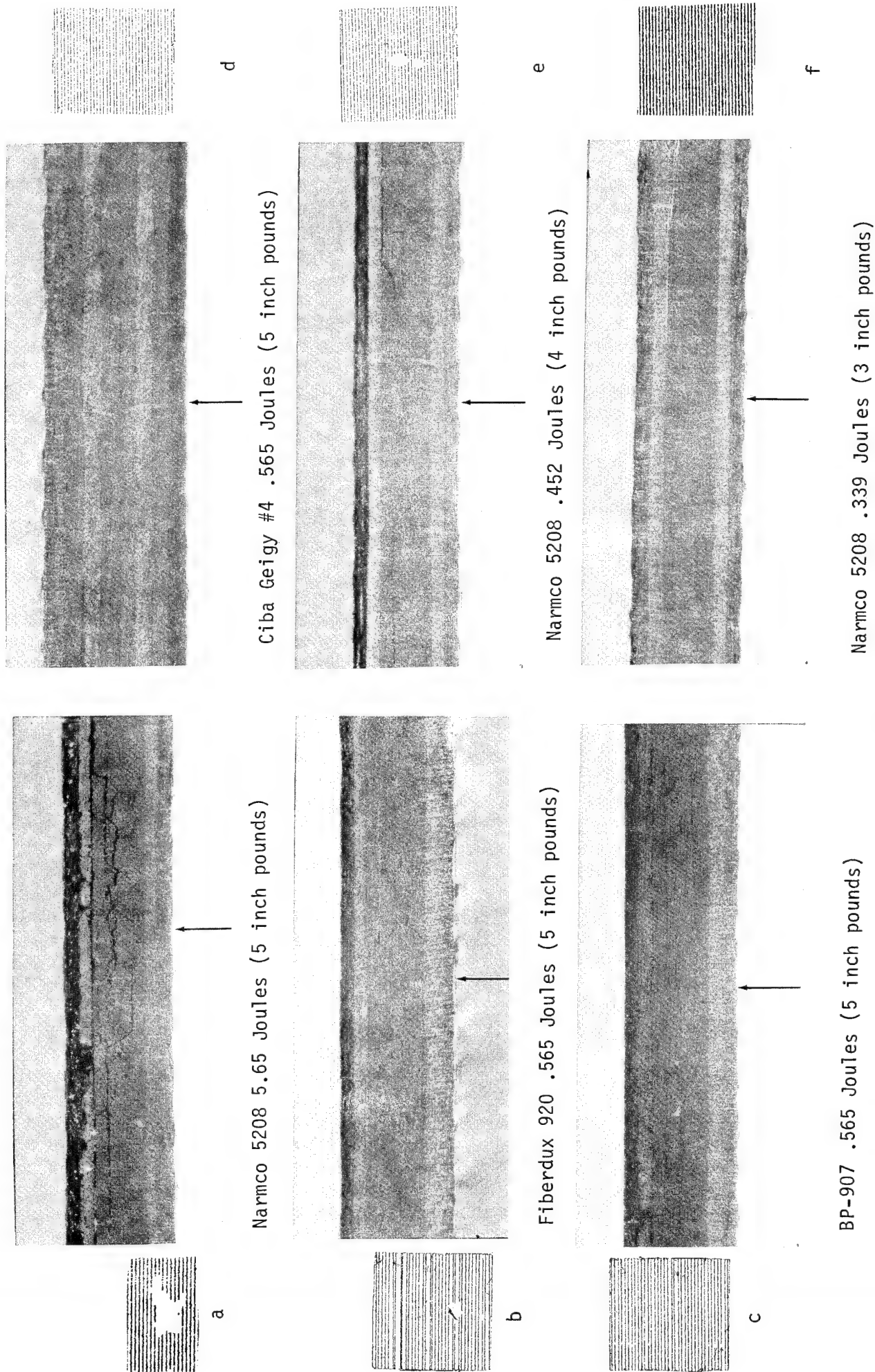


FIGURE 37. PHOTOMACROGRAPHS AT 20x AT IMPACT LEVELS BELOW VISUAL SURFACE DAMAGE

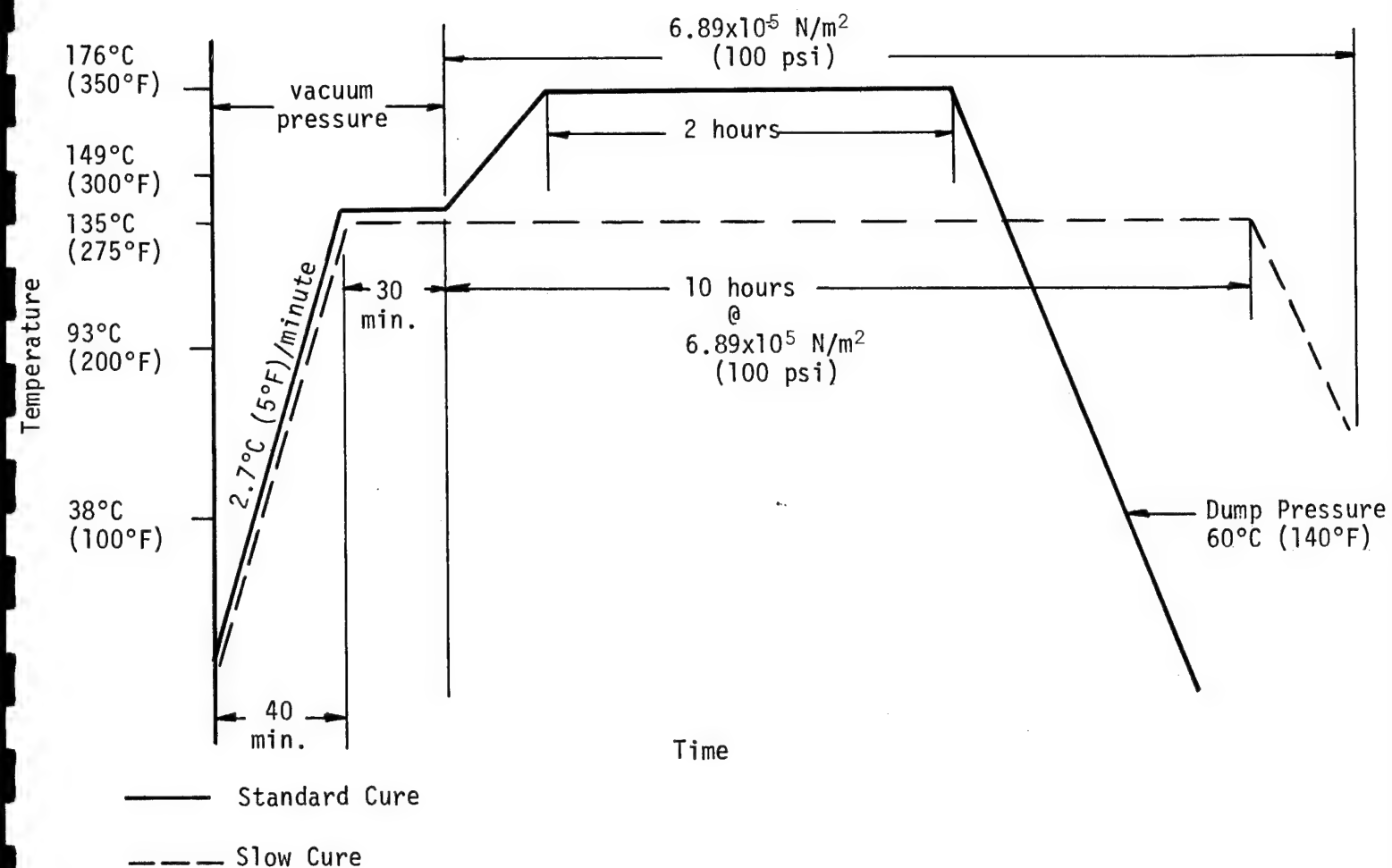


FIGURE 38. STANDARD AND SLOW CURE CYCLE FOR NARMCO 5208/T300

FIGURE 39. TWO CURING CYCLES - MECHANICAL AND IMPACT PROPERTIES

5208 REFERENCE PANEL
STANDARD CURE¹

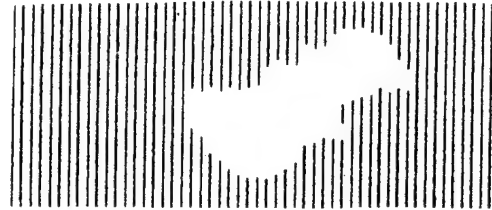
5208 SLOW CURE

TEN STR 1.5×10^9 N/m² (218,000 psi)
 TEN MOD 1.31×10^{11} N/m² (19,000,000 psi)
 COMP STR 1.45×10^9 N/m² (210,000 psi)
 COMP MOD 1.24×10^{11} N/m² (18,000,000 psi)
 SHEAR STR 1.31×10^8 N/m² (19,000 psi)

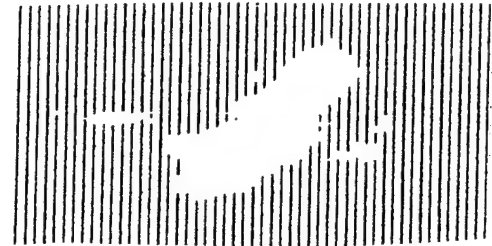
1.9×10^6 N/m² (276,000 psi)
 1.49×10^{11} N/m² (21,700,000 psi)
 1.94×10^9 N/m² (281,000 psi)
 1.34×10^{11} N/m² (19,500,000 psi)
 1.36×10^8 N/m² (19,800 psi)

C-SCAN DAMAGE
 JOULES (IN/LBS)

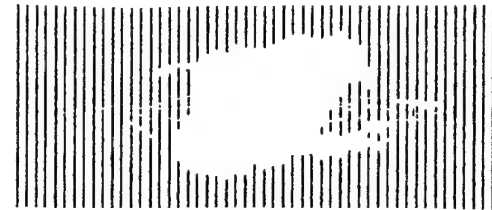
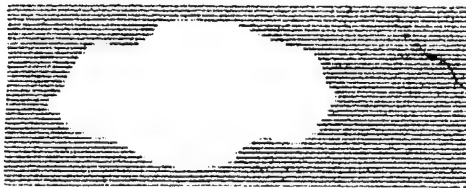
1.13
 (10)



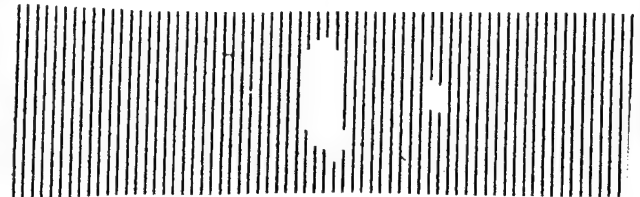
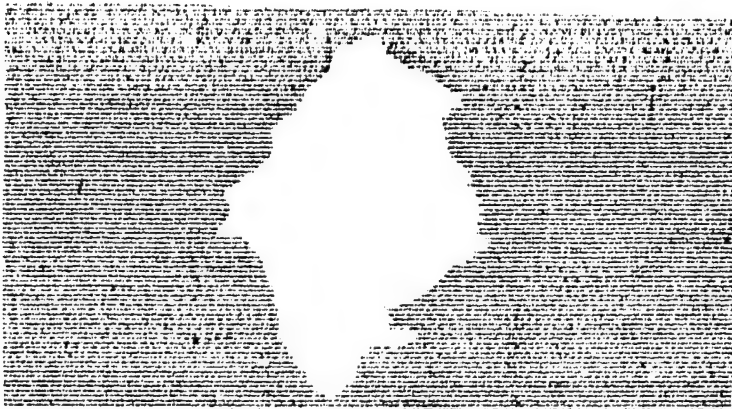
2.26
 (20)



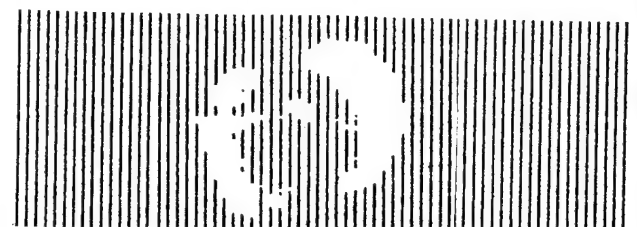
3.39
 (30)



6.87
 (60)



9.03
 (80)



damage to be higher. The impact area of damage at 6.78 (60) and 9.03 joules (80 inch pounds) was actually less than the 3.39 joules (30 inch pound) impact with the round head.

The curing cycle time/temperature/pressure conditions used to cure the neat resin specimens was always a long slow process, without pressure, and completely different than the laminate curing cycle. This infers that the reported neat resin properties are probably entirely different than the resin properties in the laminates used for mechanical and impact property tests. One material, Fiberdux 914, from Ciba Geigy, was tested for neat resin properties in two different laboratories (USA and England) on separate batches of resin. The reported resin properties are very different as shown in Table 7.

TABLE 7
NEAT RESIN PROPERTIES - TWO TEST SOURCES

TEST	ENGLAND	USA
Tensile Strength (psi)	(7,200)	(7,000)
N/M ²	4.9×10^7	4.82×10^7
Tensile Modulus (psi)	(580,000)	(280,000)
N/M ²	3.99×10^9	1.92×10^9
Elongation (%)	1.4	3

2.7 CONCLUSIONS

1. There is strong evidence that modification of the epoxy matrix resin system tensile properties can have significant influence on resultant graphite structural panel mechanical and impact properties.
2. It also is evident that considerable improvement in impact properties can be expected with no significant loss of room temperature mechanical properties. In fact, a reasonable improvement in both tensile and compression properties, as well as improved impact resistance can be predicted for future resin development programs.
3. The results of this program suggest that an improved composite matrix system should have neat resin tensile ultimate properties of over 6.89×10^7 N/M² (10,000 psi), a tensile modulus of elasticity above 3.1×10^9 N/M² (450,000 psi) and a tensile elongation of between 5 and 7%.

4. Since no testing was accomplished at elevated temperature, humidity or other environments, no inference can be drawn that these materials can be used in their present form as a commercial product.
5. Identification of commercial products in this report is used to adequately describe the test materials. Neither the identification of these commercial products nor the results of the investigation published therein constitute official endorsement, expressed or implied, of any such product by either The Douglas Aircraft Company or NASA.

2.8 RECOMMENDATIONS

1. The more promising resin systems from this development should have some level of process optimization study to develop the best available material and impact properties.
2. The best of these systems should be fabricated into panels, damaged to various levels of impact, and tested for retained strength in tensile, compression and shear load conditions.
3. The best of these materials should then be fabricated into panels, damaged and tested for propagation of damage at various fatigue stress levels.
4. The best surviving materials should be tested after environmental preconditioning (temperature, humidity, aggressive solvents, etc.), then damaged and tested again for comparative retained strength properties.
5. A tooling and processing concept should be developed for making neat resin tensile specimens that will incorporate the same time/temperature/pressure processing cycle required for the final structural panel. Only then can a true relationship between neat resin and laminate properties be developed.

2.9 REFERENCES

1. Impact Damage Tolerance of Thick Graphite/Epoxy Laminates; N. M. Bhatia, Northrup Corporation for the Naval Air Development Center; Report No. NADC-79038-60, January 1979.
2. Low-Velocity Impact Damage in Graphite Fiber Reinforced Epoxy Laminates; Marvin D. Rhodes; Jerry G. Williams; and James H. Starnes, Jr.: NASA; 34th Annual Conference on Reinforced Plastics/Composites, The Society of the Plastics Industry, January 1979.

3. Impact Damage Characteristics of Graphite/Epoxy Laminates; N. M. Bhatia, Northrup Corporation Report No. NOR 76-186, June 1977.
4. Williams, Jerry G.; Angerson, Melvin S.; Rhodes, Marvin D.; Starnes, James H.; Stroud, W. Jefferson: Recent Developments in the Design, Testing and Impact-Damage Tolerance of Stiffened Composite Panels. Fibrous Composites In Structural Design, Plenum Press, 1980. pp 259-291.

APPENDIX 1

GARDNER IMPACT DATA

The Gardner impact results are recorded in Appendix 1 for impact energy, front side visual damage, back side visual damage, "C" scan and area of "C" scan damage and certain resin and impact panel physical properties for all materials tested.

FIGURE A-1 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING NARMCO 5208 RESIN REFERENCE PANEL

RESIN TYPE	Epoxy - MY-720	THICKNESS	1.07mm (.042")
HARDENER	Aromatic Amine	% RESIN	28.0
MODIFICATION	None	VOID	1.0

Joules (in lb)	3.17cm (125") SUPPORT										9.52cm (3.75") SUPPORT									
	1.58cm (5/8") ROUND					1.58cm (5/8") ROUND					1.58cm (5/8") FLAT					1.58cm (5/8") FLAT				
	1.13(10)	2.25(20)	3.39(30)	3.39(30)	3.39(30)	1.13(10)	2.26(20)	3.39(20)	3.39(30)	4.52(40)	5.65(50)	6.78(60)	7.91(70)	9.04(80)	10.2(90)	11.3(100)	13.6(120)			
VISUAL FRONT SIDE	OK	OK	3.2mm (1/8") hole broken fibers	OK	OK	OK	OK	OK	OK	OK	OK	1.58cm (5/8") hole broken fibers	1.58cm (5/8") hole broken fibers	1.58cm (5/8") hole broken fibers & 0° cracks						
VISUAL BACK SIDE	.2 x .7 5x17.8	.3 X 1.2 7.6x30.5	.4 X 1.2 10.2x30.5	OK	OK	OK	.2 X 1.5 5x38	.3 X .3 7.6x7.6	OK	OK	OK	1.1X1.1 28x28	1.2X3.7 30.5x94							
C-SCAN -DAMAGE																				
C-SCAN cm ² DAMAGE (in ²) AREA	1.69 (.26)	3.64 (.56)	5.33 (.82)	6.43 (.99)	3.96 (.61)	0 (.00)	10	20	30	50	60	70	80	9.94 (4.53)	14.4 (2.22)					
COMMENTS	Splintering					Delamination and Some Splintering					Broken fibers and heavy delamination									

FIGURE A-2 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING NARMCO 5208 (Slow Cure)

RESIN TYPE	Epoxy MY720	THICKNESS	1.09mm (.043")
HARDENER	Aromatic Amine	% RESIN	26.4
MODIFICATION	None	VOID	

	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT									
	1.58cm (5/8") ROUND			1.58cm (5/8") FLAT									
	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.65(50)	6.78(60)	7.91(70)	9.04(80)	10.2(90)	11.3(100)
Joules (in-lbs)													
VISUAL FRONT SIDE	OK	OK	6.35mm (1/4") dent	OK	OK	6.35mm (1/4") dent			OK		OK		2.54x2.54cm (1x1") damage (1.58cm (5/8") hole broken fiber & splint.
VISUAL BACK SIDE	OK	.2x1	.3x1.2	OK	.1x1	.3x2.5					.1x.8		
C-SCAN DAMAGE	1.13	2.26	3.39	1.13	2.54	25.4	7.6x30.5		OK		2.5x20.3		
Joules	1.13	2.26	3.39	1.13	2.26	3.05	3.39	6.78	9.04	13.6			
C-SCAN DAMAGE AREA (in ²)	3.12 (.48)	2.6 (.40)	3.9 (.60)	0 (.00)	1.36 (.21)	3.05 (.47)		1.04 (.16)	2.4 (.37)				14.04 (2.16)
COMMENTS	Splintering and delamination			Cracks in 0° direction - some delamination				Broken fibers & delamination, 0° cracks Heavy splintering at 13.6 joules (120 in lbs)					

FIGURE A-3 IMPACT DAMAGE DATA FOR (0,+45/90)s Laminate Using Narmco 5208 (Resin Rich)

RESIN TYPE	Epoxy MV720	THICKNESS	1.12 (.044")
HARDENER	Aromatic Amine	% RESIN	29.9
MODIFICATION	None	VOID	0.10

	9.52cm(3.75") SUPPORT									
	3.17cm (125") SUPPORT					1.58cm (5/8") FLAT				
	1.58cm (5/8") ROUND	3.39(30)	2.26(20)	6.35mm (1/4") dent	9.5mm (3/8") dent	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)
Visual Front Side	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Visual Back Side	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
C-SCAN DAMAGE	10	20	30	10	20	30	10	20	30	40
2.54cm 1"	10	20	30	10	20	30	10	20	30	40
(in lb)	10	20	30	10	20	30	10	20	30	40
Joules	1.13	2.26	3.39	1.13	2.26	3.39	1.13	2.26	3.39	4.52
C-SCAN DAMAGE AREA (in ²)	1.36 (.21)	3.57 (.55)	4.61 (.71)	.585 (.09)	1.82 (.28)	7.93 (1.22)	10.2 (1.57)	12.15 (1.87)	16.57 (2.55)	25.4x63.5
COMMENTS	Heavy splintering and some delamination					Delamination, some splintering at 3.39 (30)				
						Broken fibers and heavy delamination slight splintering				

FIGURE A-4 IMPACT DAMAGE DATA FOR (0/+45/90) LAMINATE USING NARMCO 5208 (Resin Poor)

RESIN TYPE	Epoxy
HARDENER	Aromatic Amine
MODIFICATION	None

THICKNESS	1.02mm (.040")
% RESIN	24.6
VOID	

	9.52cm (3.75") SUPPORT									
	3.17cm (125") SUPPORT					1.58cm (5/8") FLAT				
	1.58cm (5/8") ROUND	1.13(10)	2.26(20)	3.39(30)	1.58cm (5/8") ROUND	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)
Joules(in-lbs)										
VISUAL FRONT SIDE	OK	OK	OK	3.2mm (1/8") hole broken fibers	OK	OK	OK	1/4" dent	OK	OK
VISUAL BACK SIDE	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
C-SCAN -DAMAGE	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
2.54cm 1" 0	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
C-SCAN cm ² DAMAGE AREA(in ²)	1.36 (.21)	3.96 (.61)	4.68 (.72)	9.75 (.15)	2.92 (.45)	6.3 (.97)	10.98 (1.69)	10.98 (1.69)	10.98 (1.69)	10.98 (1.69)
COMMENTS	Delamination and splintering	Delamination and splintering	Delamination and slight splintering	Delamination and slight splintering	Delamination and slight splintering	Delamination and slight splintering	Delamination and broken fibers - some splintering	Delamination and broken fibers - some splintering	Delamination and broken fibers - some splintering	Delamination and broken fibers - some splintering

FIGURE A-5 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING NARMCO 95995 RESIN REFERENCE PANEL

THICKNESS 1.04 mm (.041)
 % RESIN 32.7
 VOID 3

RESIN TYPE Epoxy
 HARDENER Aromatic Amine
 MODIFICATION

9.52 cm (3.75") SUPPORT																	
JOULES (IN-LB)	3.17cm (125") SUPPORT			1.58cm (5/8") ROUND			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	Broken fibers	OK	OK	OK	OK	OK	OK	OK	OK	5/8" dent cracks spread 90°	5/8" dent cracks spread 90°	5/8" dent 0° & 90° cracks			
VISUAL BACK SIDE	.2x.8"	.3x2	.7x2			.4x1.7						1.5x1.3		1.5x1.4			
C-SCAN DAMAGE	5.1 x 20.3	7.62 x 50.8	17.8 x 50.8	OK	OK	10.1 x 17.8	OK	OK	OK	OK	OK	38 x 33		38 x 35			
2.54cm																	
C-SCAN DAMAGE AREA in ²	1.36 (.21)	1.95 (.30)	3.70 (.57)	0 (.00)	0 (.00)	4.09 (.63)	0 (.00)	0 (.00)	10	20	30	0 (.00)	9.1 (1.40)	11.37 (1.75)			
COMMENTS	Internal delamination and splintering			Delamination			Very heavy delamination, slight splinters, numerous broken fibers, severe 90° cracks										

FIGURE A-6 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING NARMCO X107 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Bis Phenol A
HARDENER Non-Aromatic Amine
MODIFICATION Elastomers

THICKNESS 1.22mm (.048")
% RESIN 29.8
VOID 1.5

	9.52cm (3.75") SUPPORT									
	3.17cm (125") SUPPORT		1.58cm (5/8") ROUND		1.58cm (5/8") FLAT		7.91(70)		11.30(100)	
	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)
JOULES(in lb)	1.13	2.26	3.39	4.52	5.56	6.78	7.91	9.04	10.20	11.30
VISUAL FRONT SIDE	OK	OK	3.17mm (1/8") dent	OK	OK	1.9cm (.75") crack 90°	OK	5.8cm (5/8") hole 0° cracks	OK	OK
VISUAL BACK SIDE	in .1x.5	.3x.5	.5x.1	.5" crack	.1x.8	.8x.5	1.2x1	30.5 x 25.4	OK	OK
C-SCAN DAMAGE	2.54cm	7.6x12.7	12.7x2.5	12.7	2.5x20.3	20.3x12.7	OK	OK	OK	OK
2.54cm — 1" — 0	10	20	30	10	20	30	50	60	70	80
(in lbs)	1.13	2.26	3.39	1.13	2.26	3.39	5.56	6.78	9.04	
Joules	1.13	2.26	3.39	1.13	2.26	3.39	5.56	6.78	9.04	
C-SCAN DAMAGE AREA(in ²)	.65	1.5	2.4	0	1.5	2.66	0	7.47	7.41	
	(.10)	(.23)	(.37)	(.00)	(.23)	(.41)	(.00)	(1.15)	(1.14)	
COMMENTS	Broken fibers and delamination	Broken fibers and delamination	Broken fibers and slight delam. at 3.39 joules (30 in lbs)	0° cracks	Broken fibers and delamination	Broken fibers and delamination	Broken fibers and delamination	Broken fibers and delamination	Broken fibers and delamination	

FIGURE A-7 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING NARMCO X108 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A
 HARDENER Aromatic Amine
 MODIFICATION Elastomer

THICKNESS 1.02 mm (.040")
 % RESIN 24.0
 VOID 1.3

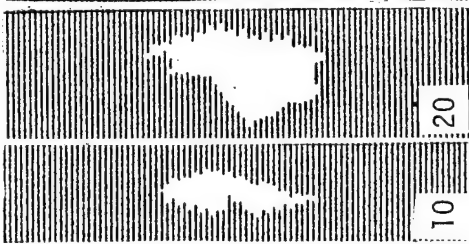

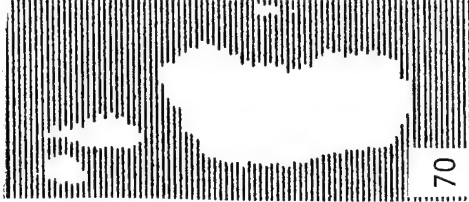
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT					
	1.58cm (5/8")	ROUND	3.39 (30)	1.58cm (5/8")	ROUND	1.58cm (5/8")	FLAT	1.58cm (5/8")	FLAT
JOULES (in lb)	1.13 (10)	2.26 (20)	3.39 (30)	1.13 (10)	2.26 (20)	3.39 (30)	4.52 (40)	5.56 (50)	6.78 (60)
VISUAL FRONT SIDE	OK	3.17 mm (1/8") dent	dent broken fibers						
VISUAL BACK SIDE	Crack 1" long	.3x1.5" 7.6x38	.4x1.5 10.2x38						
C-SCAN DAMAGE									
2.54cm 1" 0	10	20	30	60	70	80			
(in lbs)	1.13	2.26	3.39	6.78	7.91	9.04			
Joules	1.13	2.26	3.39	6.78	7.91	9.04			
C-SCAN DAMAGE AREA	.91 (14)	1.75 (.27)	2.79 (.43)				0 (0)	4.68 (.72)	7.80 (1.20)
COMMENTS	Heavy splintering - some delamination and broken fibers			At 9.04 joules (80 in lbs) broken fibers, heavy delamination slight splinters					

FIGURE A-8 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING NARMCO X109 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Bis Phenol A
 HARDENER Non Aromatic Amine
 MODIFICATION Elastomers

THICKNESS 1.19mm (.047")
 % RESIN 33.5
 VOID 1.1

	3.17cm (125") SUPPORT				9.52cm (3.75") SUPPORT				1.58cm (5/8") FLAT			
	1.58cm (5/8")	3.17cm (1 1/8")	4.76cm (1 7/8")	6.35cm (2 1/2")	1.58cm (5/8")	3.17cm (1 1/8")	4.76cm (1 7/8")	6.35cm (2 1/2")	1.58cm (5/8")	3.17cm (1 1/8")	4.76cm (1 7/8")	6.35cm (2 1/2")
	1.13(10)	2.26(20)	3.39(30)	4.52(40)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	1.13(10)	2.26(20)	3.39(30)	4.52(40)
Joules (in lb)	1.13	2.26	3.39	4.52	1.13	2.26	3.39	4.52	1.13	2.26	3.39	4.52
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	3.17mm (1/8") puncture	5x.6	OK	OK	3.17mm (1/8") dent	1.58cm (5/8") dent	OK	OK	1.58cm (5/8") dent	1.58cm (5/8") dent
VISUAL BACK SIDE	.2x.2	.3x.6	5x.6	12.7x15.2	.3"90° crack	7.6	.1x1	1.5x.8	OK	OK	1.5x.8	38x20.3
C-SCAN DAMAGE	10	20	30	10	20	30	10	20	60	80	11.30(100)	13.60(120)
2.54cm 1" (in lbs)	1.13	2.26	3.39	1.13	2.26	3.39	6.78	9.04				
Joules	1.13	2.26	3.39	1.13	2.26	3.39	6.78	9.04				
C-SCAN DAMAGE AREA (in ²)	.39 (.06)	2.01 (.31)	2.6 (.40)	0 (.00)	.84 (.13)	2.7 (.42)	0 (0.0)	9.94 (1.53)				
COMMENTS	Delamination and broken fibers				2.26 joules (20 in 1b) broken fibers				Broken fibers - some delamination			

FIGURE A-9 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING NARMCO X1114 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A

THICKNESS 1.27mm (.050")

HARDENER Non-Aromatic Amine

% RESIN 30.8

MODIFICATION Elastomers - Max.

VOID 4.7

	9.52cm (3.75") SUPPORT									
	3.17cm (125") SUPPORT		1.58cm (5/8") ROUND		1.58cm (5/8") ROUND		1.58cm (5/8") FLAT			
	1.13 (10)	2.26 (20)	3.39 (30)	6.34mm (1/4") dent	1.13 (10)	2.26 (20)	3.39 (30)	4.52 (40)	5.56 (50)	6.78 (60)
JOULES (in lb)										
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.34mm (1/4") dent				OK	dent	dent	
VISUAL BACK SIDE	OK	.2x.1	.2x.3				OK	crack propag. 1.2x.2	crack 1.0x.5	
		~	+							
		5.1 x 2.54	5.1 x 7.6					30.5 x 5.1	25.4 x 12.7	
C-SCAN DAMAGE										
	10	20	30	50	60	80				
	1.13	2.26	3.39	5.56	6.78	9.04				
C-SCAN DAMAGE AREA (in ²)	.13	.84	1.43		0	3.25	3.57			
	(.02)	(.13)	(.22)		(.00)	(.50)	(.55)			
COMMENTS	No splintering, no delamination, only damage broken fibers									
	Only damage broken fibers									

FIGURE A-10 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING AMERICAN CYANAMIDE BP907 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A
HARDENER Latent Aliphatic Amine
MODIFICATION Vinyl Resin

THICKNESS 1.24mm (.049")
% RESIN 31.7
VOID 0.6

	3.17cm (125") SUPPORT	9.52cm (3.75") SUPPORT	19.05cm (7.5") SUPPORT	25.4cm (10") SUPPORT	31.75cm (12.5") SUPPORT	38.1cm (15") SUPPORT	44.45cm (17.5") SUPPORT	50.8cm (20") SUPPORT	57.15cm (22.5") SUPPORT	63.5cm (25") SUPPORT	69.85cm (27.5") SUPPORT	76.2cm (30") SUPPORT	82.55cm (32.5") SUPPORT	88.9cm (35") SUPPORT	95.25cm (37.5") SUPPORT	101.6cm (40") SUPPORT	107.95cm (42.5") SUPPORT	114.3cm (45") SUPPORT	120.65cm (47.5") SUPPORT	127cm (50") SUPPORT	133.35cm (52.5") SUPPORT	139.7cm (55") SUPPORT	146.05cm (57.5") SUPPORT	152.4cm (60") SUPPORT	158.75cm (62.5") SUPPORT	165.1cm (65") SUPPORT	171.45cm (67.5") SUPPORT	177.8cm (70") SUPPORT	184.15cm (72.5") SUPPORT	190.5cm (75") SUPPORT	196.85cm (77.5") SUPPORT	203.2cm (80") SUPPORT	209.55cm (82.5") SUPPORT	215.9cm (85") SUPPORT	222.25cm (87.5") SUPPORT	228.6cm (90") SUPPORT	234.95cm (92.5") SUPPORT	241.3cm (95") SUPPORT	247.65cm (97.5") SUPPORT	254cm (100") SUPPORT	260.35cm (102.5") SUPPORT	266.7cm (105") SUPPORT	273.05cm (107.5") SUPPORT	279.4cm (110") SUPPORT	285.75cm (112.5") SUPPORT	292.1cm (115") SUPPORT	298.45cm (117.5") SUPPORT	304.8cm (120") SUPPORT	311.15cm (122.5") SUPPORT	317.5cm (125") SUPPORT	323.85cm (127.5") SUPPORT	330.2cm (130") SUPPORT	336.55cm (132.5") SUPPORT	342.9cm (135") SUPPORT	349.25cm (137.5") SUPPORT	355.6cm (140") SUPPORT	361.95cm (142.5") SUPPORT	368.3cm (145") SUPPORT	374.65cm (147.5") SUPPORT	381cm (150") SUPPORT	387.35cm (152.5") SUPPORT	393.7cm (155") SUPPORT	400.05cm (157.5") SUPPORT	406.4cm (160") SUPPORT	412.75cm (162.5") SUPPORT	419.1cm (165") SUPPORT	425.45cm (167.5") SUPPORT	431.8cm (170") SUPPORT	438.15cm (172.5") SUPPORT	444.5cm (175") SUPPORT	450.85cm (177.5") SUPPORT	457.2cm (180") SUPPORT	463.55cm (182.5") SUPPORT	469.9cm (185") SUPPORT	476.25cm (187.5") SUPPORT	482.6cm (190") SUPPORT	488.95cm (192.5") SUPPORT	495.3cm (195") SUPPORT	501.65cm (197.5") SUPPORT	508cm (200") SUPPORT	514.35cm (202.5") SUPPORT	520.7cm (205") SUPPORT	527.05cm (207.5") SUPPORT	533.4cm (210") SUPPORT	539.75cm (212.5") SUPPORT	546.1cm (215") SUPPORT	552.45cm (217.5") SUPPORT	558.8cm (220") SUPPORT	565.15cm (222.5") SUPPORT	571.5cm (225") SUPPORT	577.85cm (227.5") SUPPORT	584.2cm (230") SUPPORT	590.55cm (232.5") SUPPORT	596.9cm (235") SUPPORT	603.25cm (237.5") SUPPORT	609.6cm (240") SUPPORT	615.95cm (242.5") SUPPORT	622.3cm (245") SUPPORT	628.65cm (247.5") SUPPORT	635cm (250") SUPPORT	641.35cm (252.5") SUPPORT	647.7cm (255") SUPPORT	654.05cm (257.5") SUPPORT	660.4cm (260") SUPPORT	666.75cm (262.5") SUPPORT	673.1cm (265") SUPPORT	679.45cm (267.5") SUPPORT	685.8cm (270") SUPPORT	692.15cm (272.5") SUPPORT	698.5cm (275") SUPPORT	704.85cm (277.5") SUPPORT	711.2cm (280") SUPPORT	717.55cm (282.5") SUPPORT	723.9cm (285") SUPPORT	730.25cm (287.5") SUPPORT	736.6cm (290") SUPPORT	742.95cm (292.5") SUPPORT	749.3cm (295") SUPPORT	755.65cm (297.5") SUPPORT	762cm (300") SUPPORT	768.35cm (302.5") SUPPORT	774.7cm (305") SUPPORT	781.05cm (307.5") SUPPORT	787.4cm (310") SUPPORT	793.75cm (312.5") SUPPORT	800.1cm (315") SUPPORT	806.45cm (317.5") SUPPORT	812.8cm (320") SUPPORT	819.15cm (322.5") SUPPORT	825.5cm (325") SUPPORT	831.85cm (327.5") SUPPORT	838.2cm (330") SUPPORT	844.55cm (332.5") SUPPORT	850.9cm (335") SUPPORT	857.25cm (337.5") SUPPORT	863.6cm (340") SUPPORT	869.95cm (342.5") SUPPORT	876.3cm (345") SUPPORT	882.65cm (347.5") SUPPORT	889cm (350") SUPPORT	895.35cm (352.5") SUPPORT	901.7cm (355") SUPPORT	908.05cm (357.5") SUPPORT	914.4cm (360") SUPPORT	920.75cm (362.5") SUPPORT	927.1cm (365") SUPPORT	933.45cm (367.5") SUPPORT	939.8cm (370") SUPPORT	946.15cm (372.5") SUPPORT	952.5cm (375") SUPPORT	958.85cm (377.5") SUPPORT	965.2cm (380") SUPPORT	971.55cm (382.5") SUPPORT	977.9cm (385") SUPPORT	984.25cm (387.5") SUPPORT	990.6cm (390") SUPPORT	996.95cm (392.5") SUPPORT	1003.3cm (395") SUPPORT	1009.65cm (397.5") SUPPORT	1016cm (400") SUPPORT	1022.35cm (402.5") SUPPORT	1028.7cm (405") SUPPORT	1035.05cm (407.5") SUPPORT	1041.4cm (410") SUPPORT	1047.75cm (412.5") SUPPORT	1054.1cm (415") SUPPORT	1060.45cm (417.5") SUPPORT	1066.8cm (420") SUPPORT	1073.15cm (422.5") SUPPORT	1079.5cm (425") SUPPORT	1085.85cm (427.5") SUPPORT	1092.2cm (430") SUPPORT	1098.55cm (432.5") SUPPORT	1104.9cm (435") SUPPORT	1111.25cm (437.5") SUPPORT	1117.6cm (440") SUPPORT	1123.95cm (442.5") SUPPORT	1130.3cm (445") SUPPORT	1136.65cm (447.5") SUPPORT	1143cm (450") SUPPORT	1149.35cm (452.5") SUPPORT	1155.7cm (455") SUPPORT	1162.05cm (457.5") SUPPORT	1168.4cm (460") SUPPORT	1174.75cm (462.5") SUPPORT	1181.1cm (465") SUPPORT	1187.45cm (467.5") SUPPORT	1193.8cm (470") SUPPORT	1200.15cm (472.5") SUPPORT	1206.5cm (475") SUPPORT	1212.85cm (477.5") SUPPORT	1219.2cm (480") SUPPORT	1225.55cm (482.5") SUPPORT	1231.9cm (485") SUPPORT	1238.25cm (487.5") SUPPORT	1244.6cm (490") SUPPORT	1250.95cm (492.5") SUPPORT	1257.3cm (495") SUPPORT	1263.65cm (497.5") SUPPORT	1270cm (500") SUPPORT	1276.35cm (502.5") SUPPORT	1282.7cm (505") SUPPORT	1289.05cm (507.5") SUPPORT	1295.4cm (510") SUPPORT	1301.75cm (512.5") SUPPORT	1308.1cm (515") SUPPORT	1314.45cm (517.5") SUPPORT	1320.8cm (520") SUPPORT	1327.15cm (522.5") SUPPORT	1333.5cm (525") SUPPORT	1339.85cm (527.5") SUPPORT	1346.2cm (530") SUPPORT	1352.55cm (532.5") SUPPORT	1358.9cm (535") SUPPORT	1365.25cm (537.5") SUPPORT	1371.6cm (540") SUPPORT	1377.95cm (542.5") SUPPORT	1384.3cm (545") SUPPORT	1390.65cm (547.5") SUPPORT	1397cm (550") SUPPORT	1403.35cm (552.5") SUPPORT	1409.7cm (555") SUPPORT	1416.05cm (557.5") SUPPORT	1422.4cm (560") SUPPORT	1428.75cm (562.5") SUPPORT	1435.1cm (565") SUPPORT	1441.45cm (567.5") SUPPORT	1447.8cm (570") SUPPORT	1454.15cm (572.5") SUPPORT	1460.5cm (575") SUPPORT	1466.85cm (577.5") SUPPORT	1473.2cm (580") SUPPORT	1479.55cm (582.5") SUPPORT	1485.9cm (585") SUPPORT	1492.25cm (587.5") SUPPORT	1498.6cm (590") SUPPORT	1504.95cm (592.5") SUPPORT	1511.3cm (595") SUPPORT	1517.65cm (597.5") SUPPORT	1524cm (600") SUPPORT	1530.35cm (602.5") SUPPORT	1536.7cm (605") SUPPORT	1543.05cm (607.5") SUPPORT	1549.4cm (610") SUPPORT	1555.75cm (612.5") SUPPORT	1562.1cm (615") SUPPORT	1568.45cm (617.5") SUPPORT	1574.8cm (620") SUPPORT	1581.15cm (622.5") SUPPORT	1587.5cm (625") SUPPORT	1593.85cm (627.5") SUPPORT	1600.2cm (630") SUPPORT	1606.55cm (632.5") SUPPORT	1612.9cm (635") SUPPORT	1619.25cm (637.5") SUPPORT	1625.6cm (640") SUPPORT	1631.95cm (642.5") SUPPORT	1638.3cm (645") SUPPORT	1644.65cm (647.5") SUPPORT	1651cm (650") SUPPORT	1657.35cm (652.5") SUPPORT	1663.7cm (655") SUPPORT	1670.05cm (657.5") SUPPORT	1676.4cm (660") SUPPORT	1682.75cm (662.5") SUPPORT	1689.1cm (665") SUPPORT	1695.45cm (667.5") SUPPORT	1701.8cm (670") SUPPORT	1708.15cm (672.5") SUPPORT	1714.5cm (675") SUPPORT	1720.85cm (677.5") SUPPORT	1727.2cm (680") SUPPORT	1733.55cm (682.5") SUPPORT	1739.9cm (685") SUPPORT	1746.25cm (687.5") SUPPORT	1752.6cm (690") SUPPORT	1758.95cm (692.5") SUPPORT	1765.3cm (695") SUPPORT	1771.65cm (697.5") SUPPORT	1778cm (700") SUPPORT	1784.35cm (702.5") SUPPORT	1790.7cm (705") SUPPORT	1797.05cm (707.5") SUPPORT	1803.4cm (710") SUPPORT	1809.75cm (712.5") SUPPORT	1816.1cm (715") SUPPORT	1822.45cm (717.5") SUPPORT	1828.8cm (720") SUPPORT	1835.15cm (722.5") SUPPORT	1841.5cm (725") SUPPORT	1847.85cm (727.5") SUPPORT	1854.2cm (730") SUPPORT	1860.55cm (732.5") SUPPORT	1866.9cm (735") SUPPORT	1873.25cm (737.5") SUPPORT	1879.6cm (740") SUPPORT	1885.95cm (742.5") SUPPORT	1892.3cm (745") SUPPORT	1898.65cm (747.5") SUPPORT	1905cm (750") SUPPORT	1911.35cm (752.5") SUPPORT	1917.7cm (755") SUPPORT	1924.05cm (757.5") SUPPORT	1930.4cm (760") SUPPORT	1936.75cm (762.5") SUPPORT	1943.1cm (765") SUPPORT	1949.45cm (767.5") SUPPORT	1955.8cm (770") SUPPORT	1962.15cm (772.5") SUPPORT	1968.5cm (775") SUPPORT	1974.85cm (777.5") SUPPORT	1981.2cm (780") SUPPORT	1987.55cm (782.5") SUPPORT	1993.9cm (785") SUPPORT	2000.25cm (787.5") SUPPORT	2006.6cm (790") SUPPORT	2012.95cm (792.5") SUPPORT	2019.3cm (795") SUPPORT	2025.65cm (797.5") SUPPORT	2032cm (800") SUPPORT	2038.35cm (802.5") SUPPORT	2044.7cm (805") SUPPORT	2051.05cm (807.5") SUPPORT	2057.4cm (810") SUPPORT	2063.75cm (812.5") SUPPORT	2070.1cm (815") SUPPORT	2076.45cm (817.5") SUPPORT	2082.8cm (820") SUPPORT	2089.15cm (822.5") SUPPORT	2095.5cm (825") SUPPORT	2101.85cm (827.5") SUPPORT	2108.2cm (830") SUPPORT	2114.55cm (832.5") SUPPORT	2120.9cm (835") SUPPORT	2127.25cm (837.5") SUPPORT	2133.6cm (840") SUPPORT	2139.95cm (842.5") SUPPORT	2146.3cm (845") SUPPORT	2152.65cm (847.5") SUPPORT	2159cm (850") SUPPORT	2165.35cm (852.5") SUPPORT	2171.7cm (855") SUPPORT	2178.05cm (857.5") SUPPORT	2184.4cm (860") SUPPORT	2190.75cm (862.5") SUPPORT	2197.1cm (865") SUPPORT	2203.45cm (867.5") SUPPORT	2209.8cm (870") SUPPORT	2216.15cm (872.5") SUPPORT	2222.5cm (875") SUPPORT	2228.85cm (877.5") SUPPORT	2235.2cm (880") SUPPORT	2241.55cm (882.5") SUPPORT	2247.9cm (885") SUPPORT	2254.25cm (887.5") SUPPORT	2260.6cm (890") SUPPORT	2266.95cm (892.5") SUPPORT	2273.3cm (895") SUPPORT	2279.65cm (897.5") SUPPORT	2286cm (900") SUPPORT	2292.35cm (902.5") SUPPORT	2298.7cm (905") SUPPORT	2305.05cm (907.5") SUPPORT	2311.4cm (910") SUPPORT	2317.75cm (912.5") SUPPORT	2324.1cm (915") SUPPORT	2330.45cm (917.5") SUPPORT	2336.8cm (920") SUPPORT	2343.15cm (922.5") SUPPORT	2349.5cm (925") SUPPORT	2355.85cm (927.5") SUPPORT	2362.2cm (930") SUPPORT	2368.55cm (932.5") SUPPORT	2374.9cm (935") SUPPORT	2381.25cm (937.5") SUPPORT	2387.6cm (940") SUPPORT	2393.95cm (942.5") SUPPORT	2400.3cm (945") SUPPORT	2406.65cm (947.5") SUPPORT	2413cm (950") SUPPORT	2419.35cm (952.5") SUPPORT	2425.7cm (955") SUPPORT	2432.05cm (957.5") SUPPORT	2438.4cm (960") SUPPORT	2444.75cm (962.5") SUPPORT	2451.1cm (965") SUPPORT	2457.45cm (967.5") SUPPORT	2463.8cm (970") SUPPORT	2470.15cm (972.5") SUPPORT	2476.5cm (975") SUPPORT	2482.85cm (977.5") SUPPORT	2489.2cm (980") SUPPORT	2495.55cm (982.5") SUPPORT	2501.9cm (985") SUPPORT	2508.25cm (987.5") SUPPORT	2514.6cm (990") SUPPORT	2520.95cm (992.5") SUPPORT	2527.3cm (995") SUPPORT	2533.65cm (997.5") SUPPORT	2540cm (1000") SUPPORT	2546.35cm (1002.5") SUPPORT	2552.7cm (1005") SUPPORT	2559.05cm (1007.5") SUPPORT	2565.4cm (1010") SUPPORT	2571.75cm (1012.5") SUPPORT	2578.1cm (1015") SUPPORT	2584.45cm (1017.5") SUPPORT	2590.8cm (1020") SUPPORT	2597.15cm (1022.5") SUPPORT	2603.5cm (1025") SUPPORT	2609.85cm (1027.5") SUPPORT	2616.2cm (1030") SUPPORT	2622.55cm (1032.5") SUPPORT	2628.9cm (1035") SUPPORT	2635.25cm (1037.5") SUPPORT	2641.6cm (1040") SUPPORT	2647.95cm (1042.5") SUPPORT	2654.3cm (1045") SUPPORT	2660.65cm (1047.5") SUPPORT	2667cm (1050") SUPPORT	2673.35cm (1052.5") SUPPORT	2679.7cm (1055") SUPPORT	2686.05cm (1057.5") SUPPORT	2692.4cm (1060") SUPPORT	2698.75cm (1062.5") SUPPORT	2705.1cm (1065") SUPPORT	2711.45cm (1067.5") SUPPORT	2717.8cm (1070") SUPPORT	2724.15cm (1072.5") SUPPORT	2730.5cm (1075") SUPPORT	2736.85cm (1077.5") SUPPORT	2743.2cm (1080") SUPPORT	2749.55cm (1082.5") SUPPORT	2755.9cm (1085") SUPPORT	2762.25cm (1087.5") SUPPORT	2768.6cm (1090") SUPPORT	2774.95cm (1092.5") SUPPORT	2781.3cm (1095") SUPPORT	2787.65cm (1097.5") SUPPORT	2794cm (1100") SUPPORT	2800.35cm (1102.5") SUPPORT	2806.7cm (1105") SUPPORT	2813.05cm (1107.5") SUPPORT	2819.4cm (1110") SUPPORT	2825.75cm (1112.5") SUPPORT	2832.1cm (1115") SUPPORT	2838.45cm (1117.5") SUPPORT	2844.8cm (1120") SUPPORT	2851.15cm (1122.5") SUPPORT	2857.5cm (1125") SUPPORT	2863.85cm (1127.5") SUPPORT	2870.2cm (1130") SUPPORT	2876.55cm (1132.5") SUPPORT	2882.9cm (1135") SUPPORT	2889.25cm (1137.5") SUPPORT	2895.6cm (1140") SUPPORT	2901.95cm (1142.5") SUPPORT	2908.3cm (1145") SUPPORT	2914.65cm (1147.5") SUPPORT	2921cm (1150") SUPPORT	2927.35cm (1152.5") SUPPORT	2933.7cm (1155") SUPPORT	2940.05cm (1157.5") SUPPORT	2946.4cm (1160") SUPPORT	2952.75cm (1162.5") SUPPORT	2959.1cm (1165") SUPPORT	2965.45cm (1167.5") SUPPORT	2971.8cm (1170") SUPPORT	2978.15cm (1172.5") SUPPORT	2984.5cm (1175") SUPPORT	2990.85cm (1177.5") SUPPORT	2997.2cm (1180") SUPPORT	3003.55cm (1182.5") SUPPORT	3009.9cm (1185") SUPPORT	3016.25cm (1187.5") SUPPORT	3022.6cm (1190") SUPPORT	3028.95cm (1192.5") SUPPORT	3035.3cm (1195") SUPPORT	3041.65cm (1197.5") SUPPORT	3048cm (1200") SUPPORT	3054.35cm (1202.5") SUPPORT	3060.7cm (1205") SUPPORT	3067.05cm (1207.5") SUPPORT	3073.4cm (1210") SUPPORT	3079.75cm (1212.5") SUPPORT	3086.1cm (1215") SUPPORT	3092.45cm (1217.5") SUPPORT	3098.8cm (1220") SUPPORT	3105.15cm (1222.5") SUPPORT	3111.5cm (1225") SUPPORT	3117.85cm (1227.5") SUPPORT	3124.2cm (1230") SUPPORT	3130.55cm (1232.5") SUPPORT	3136.9cm (1235") SUPPORT	3143.25cm (1237.5") SUPPORT	3149.6cm (1240") SUPPORT	3155.95cm (1242.5") SUPPORT	3162.3cm (1245") SUPPORT	3168.65cm (1247.5") SUPPORT	3175cm (1250") SUPPORT	3181.35cm (1252.5") SUPPORT	3187.7cm (1255") SUPPORT	3194.05cm (1257.5") SUPPORT	3200.4cm (1260") SUPPORT	3206.75cm (1262.5") SUPPORT	3213.1cm (1265") SUPPORT	3219.45cm (1267.5") SUPPORT	3225.8cm (1270") SUPPORT	3232.15cm (1272.5") SUPPORT	3238.5cm (1275") SUPPORT	3244.85cm (1277.5") SUPPORT	3251.2cm (1280") SUPPORT	3257.55cm (1282.5") SUPPORT	3263.9cm (1285") SUPPORT	3270.25cm (1287.5") SUPPORT	3276.6cm (1290") SUPPORT	3282.95cm (1292.5") SUPPORT	3289.3cm (1295") SUPPORT	3295.65cm (1297.5") SUPPORT	3302cm (1300") SUPPORT	3308.35cm (1302.5") SUPPORT	3314.7cm (1305") SUPPORT	3321.05cm (1307.5") SUPPORT	3327.4cm (1310") SUPPORT	3333.75cm (1312.5") SUPPORT	3340.1cm (1315") SUPPORT	3346.45cm (1317.5") SUPPORT	3352.8cm (1320") SUPPORT	3359.15cm (1322.5") SUPPORT	3365.5cm (1325") SUPPORT	3371.85cm (1327.5") SUPPORT	3378.2cm (1330") SUPPORT	3384.55cm (1332.5") SUPPORT	3390.9cm (1335") SUPPORT	3397.25cm (1337.5") SUPPORT	3403.6cm (1340") SUPPORT	3409.95cm (1342.5") SUPPORT	3416.3cm (1345") SUPPORT	3422.65cm (1347.5") SUPPORT	3429cm (1350") SUPPORT	3435.35cm (1352.5") SUPPORT	3441.7cm (1355") SUPPORT	3448.05cm (1357.5") SUPPORT	3454.4cm (1360") SUPPORT	3460.75cm (1362.5") SUPPORT	3467.1cm (1365") SUPPORT	3473.45cm (1367.5") SUPPORT	3479.8cm (1370") SUPPORT	3486.15cm (1372.5") SUPPORT	3492.5cm (1375") SUPPORT	3498.85cm (1377.5") SUPPORT	3505.2cm (1380") SUPPORT	3511.55cm (1382.5") SUPPORT	3517.9cm (1385") SUPPORT	3524.25cm (1387.5") SUPPORT	3530.6cm (1390") SUPPORT	3536.95cm (1392.5") SUPPORT	3543.3cm (1395") SUPPORT	3549.65cm (1397.5") SUPPORT	3556cm (1400") SUPPORT	3562.35cm (1402.5") SUPPORT	3568.7cm (1405") SUPPORT	3575.05cm (1407.5") SUPPORT	3581.4cm (1410") SUPPORT	3587.75cm (1412.5") SUPPORT	3594.1cm (1415") SUPPORT	3600.45cm (1417.5") SUPPORT	3606.8cm (1420") SUPPORT	3613.15cm (1422.5") SUPPORT	3619.5cm (1425") SUPPORT	3625.85cm (1427.5") SUPPORT	3632.2cm (1430") SUPPORT	3638.55cm (1432.5") SUPPORT	3644.9cm (1435") SUPPORT	3651.25cm (1437.5") SUPPORT	3657.6cm (1440") SUPPORT	3663.95cm (1442.5") SUPPORT	3670.3cm (1445") SUPPORT	3676.65cm (1447.5") SUPPORT	3683cm (1450") SUPPORT	3689.35cm (1452.5") SUPPORT	3695.7cm (1455") SUPPORT	3702.05cm (1457.5") SUPPORT	3708.4cm (1460") SUPPORT	3714.75cm (1462.5") SUPPORT	3721.1cm (1465") SUPPORT	3727.45cm (1467.5") SUPPORT	3733.8cm (1470") SUPPORT	3740.15cm (1472.5") SUPPORT	3746.5cm (1475") SUPPORT	3752.85cm (1477.5") SUPPORT	3759.2cm (1480") SUPPORT	3765.55cm (1482.5") SUPPORT	3771.9cm (1485") SUPPORT	3778.25cm (1487.5") SUPPORT	3784.6cm (1490") SUPPORT	3790.95cm (1492.5") SUPPORT	3797.3cm (1495") SUPPORT	3803.65cm (1497.5") SUPPORT	3810cm (1500") SUPPORT	3816.35cm (1502.5") SUPPORT	3822.7cm (1505") SUPPORT	3829.05cm (1507.5") SUPPORT	3835.4cm (1510") SUPPORT	3841.75cm (1512.5") SUPPORT	3848.1cm (1515") SUPPORT	3854.45cm (1517.5") SUPPORT	3860.8cm (1520") SUPPORT	3867.15cm (1522.5") SUPPORT	3873.5cm (1525") SUPPORT	3879.85cm (1527.5") SUPPORT	3886.2cm (1530") SUPPORT	3892.55cm (1532.5") SUPPORT	3898.9cm (1535") SUPPORT	3905.25cm (1537.5") SUPPORT	3911.6cm (1540") SUPPORT	3917.95cm (1542.5") SUPPORT	3924.3cm (1545") SUPPORT	3930.65cm (1547.5") SUPPORT	3937cm (1550") SUPPORT	3943.35cm (1552.5") SUPPORT	3949.7cm (1555") SUPPORT	3956.05cm (1557.5") SUPPORT	3962.4cm (1560") SUPPORT	3968.75cm (1562.5")
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FIGURE A-11 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING AMERICAN CYANAMIDE 907 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis Phenol A
 HARDENER Latent Aliphatic Amine
 MODIFICATION Vinyl Resin

THICKNESS 1.17 mm (0.46")

% RESIN 31.4

VOID 0.3

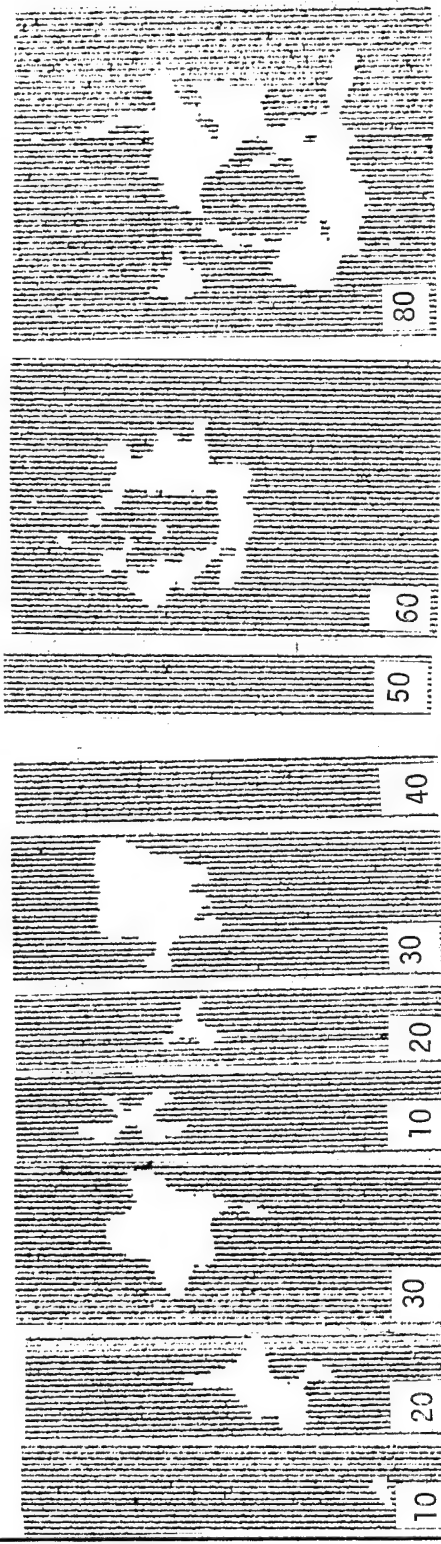
	3.17cm (125") SUPPORT		9.52cm (3.75") SUPPORT					19.05cm (7.5") FLAT				
	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND
	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.65(50)	6.78(60)	7.91(70)	9.04(80)	10.17(90)	11.30(100)	12.43(110)	13.56(120)
JOULES(in lb)												
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.34mm (1/4") dent broken fibers	OK	OK	OK	OK	15.8mm (5/8") dent broken fibers	19.05x15.8mm (3/4x5/8") hole cracks spread 0° & 90°			
VISUAL BACK SIDE	.2x.2	.2x.4	.7x.8					.8x1.5	.8x2			
mm	5.1x5.1	5.1x10.2	17.8x20	OK	OK	OK	OK	20x38	20x51			
C-SCAN DAMAGE												
(in lbs)	1.13	2.26	3.39	4.52	5.65	6.78	7.91	9.04	10.17	11.30	12.43	13.56
Joules	1.13	2.26	3.39	4.52	5.65	6.78	7.91	9.04	10.17	11.30	12.43	13.56
C-SCAN DAMAGE AREA (in²)	.065	1.04	1.3	.39	.65	1.82	0	0	3.77	6.11		
	(.01)	(.16)	(.20)	(.06)	(.1)	(.28)	(.00)	(.00)	(.58)	(.94)		
COMMENTS	Broken fibers, some delamination No visible damage Laminate pushed through, heavy with broken fibers, cracks spread in 0° & 90°. Some delamination.											

FIGURE A-12 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING AMERICAN CYANAMIDE 919 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Novalak and Bis Phenol A
 HARDENER Latent Aliphatic Amine
 MODIFICATION Elastomer

THICKNESS 1.02mm (.040")
 % RESIN 31.7
 VOID -2.8

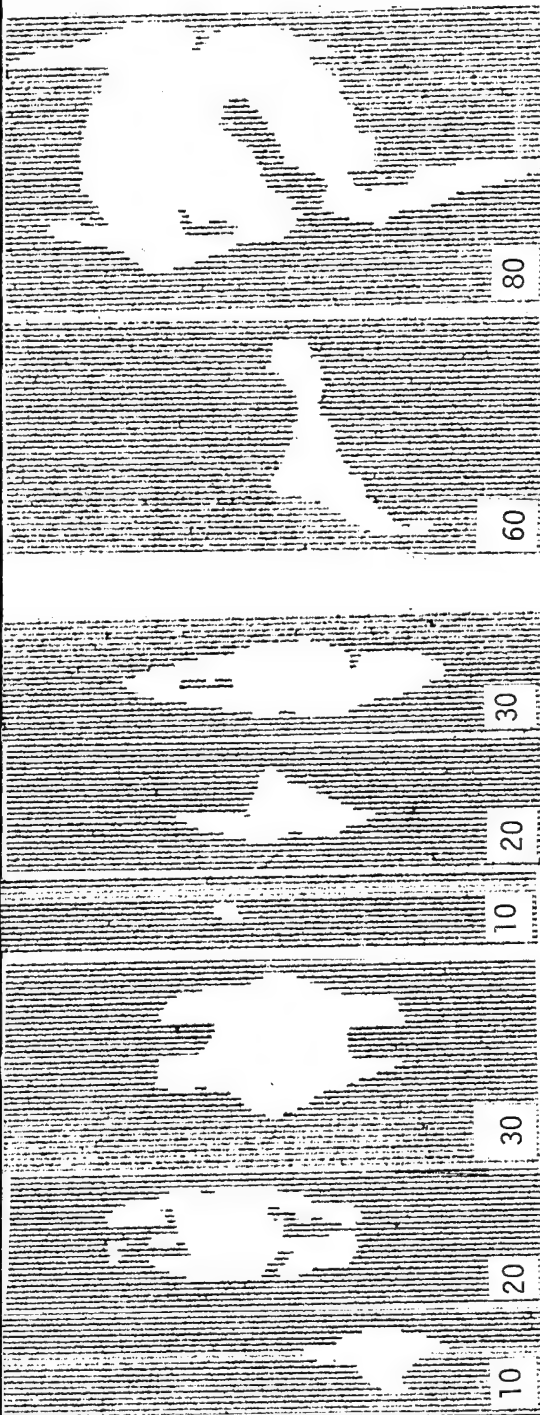
9.52cm (3.75") SUPPORT													
3.17cm (125") SUPPORT		1.58cm (5/8") ROUND											
1.58cm (5/8") ROUND		1.58cm (5/8") FLAT											
JOULES(in lb)		1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)	
VISUAL FRONT SIDE	OK	6.34mm (1/4") dent	dent broken fibers	OK	OK	OK	OK	OK	15.8cm (5/8") hole broken fiber 90° cracks				
VISUAL BACK SIDE	in. 2x1"	.3x1.2	.4x.12	OK	.3x.7"	1.2" crack			1x.5				
	mm 5.1x25.4	7.6x30.5	10.2x30.5		7.6x17.8	30.5			25.4x12.7				
C-SCAN DAMAGE													
		10	20	30	10	20	30	60	80				
C-SCANcm ² DAMAGE AREA (in ²)	1.3	3.18	3.90	.26	1.36	2.99			2.08		10.85		
	.20	.49	.60	.04	.21	.46			.32		1.67		
COMMENTS	Heavy splintering			Delamination and some broken fibers, no splintering			Broken fibers at 9.04 joules (80 in-lbs) broke through laminate.						

FIGURE A-13 IMPACT DAMAGE DATA FOR (O/+45/90)s LAMINATE USING AMERICAN CYANAMIDE 937 RESIN REFERENCE PANEL

RESIN TYPE Epoxy - Bis A & Specialty THICKNESS 1.09mm (.043")
HARDENER Latent Aromatic and Aliphatic Amines % RESIN 31.7
MODIFICATION Elastomers VOID -1.4

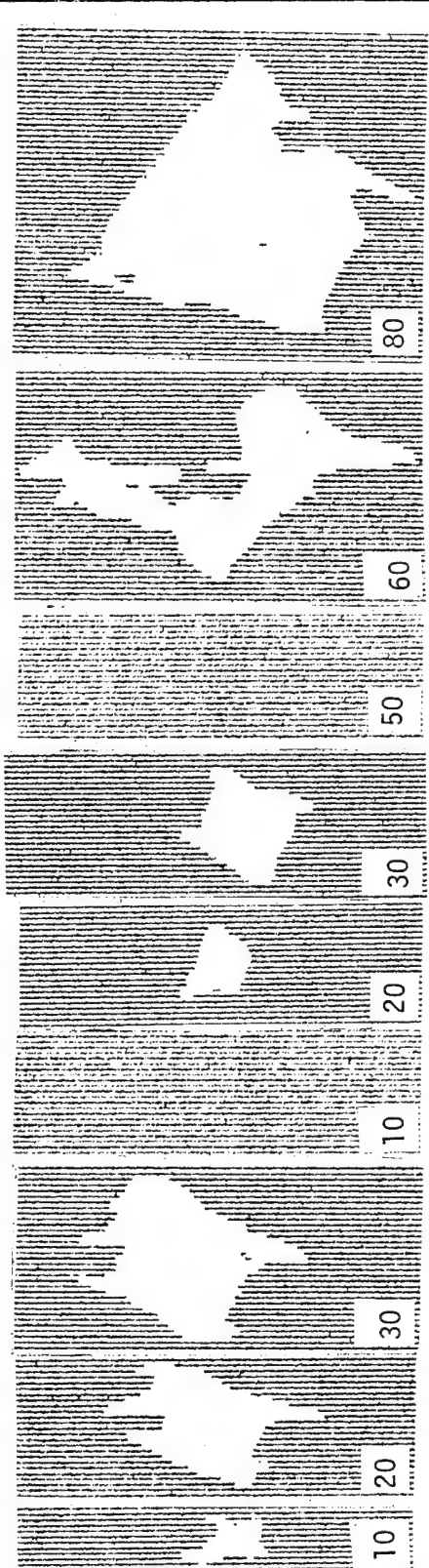
		9.52cm(3.75") SUPPORT													
3.17cm (125") SUPPORT		1.58cm (5/8") ROUND						1.58cm (5/8") FLAT							
JOULES(in lb)		1.13(0)	2.26(20)	3.39(30)	1.13(0)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE		OK	OK	dent broken fibers	OK	OK	OK		OK	Cracks 0°		1.58cm dent - broken fibers and 0° cracks			
VISUAL BACK SIDE	in	.2x.1	.5x1.2	.7x1.3	OK	.3x.2	.6x.4			.5x2		1.3x1.5			
	mm	5.1x2.54	12.7x30.5	17.8x33	OK	7.6x5.1	15.2x10.2			12.7x50.8		33x38			
C-SCAN DAMAGE															
	(in lb)	10	20	30	10	20	30	30	50	60	80				
	Joules	1.13	2.26	3.39	1.13	2.26	3.39	5.56	6.78	9.04					
C-SCAN ² DAMAGE AREA (in ²)		.455 (.07)	2.67 (.41)	4.29 (.66)	0 (.00)	.78 (.12)	1.30 (.20)		4.61 (.71)	9.03 (1.39)					
COMMENTS		Broken fibers & delamination, some splintering			Delamination and broken fibers			Heavy delamination, broken fibers and slight splintering							

FIGURE A-14 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING AMERICAN CYANAMIDE 982 RESIN REFERENCE PANEL

RESIN TYPE Epoxy Novalak & Bis Phenol A

THICKNESS 1.07mm (0.42")

HARDENER Latent Aromatic and Aliphatic Amines

% RESIN 27.0

MODIFICATION None

VOID 0.7

	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT							1.58cm (5/8") ROUND			1.58cm (5/8") FLAT						
	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND
JOULES(in lb)	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND
VISUAL FRONT SIDE	OK	6.34cm (1/4") dent	dent broken fibers	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
VISUAL BACK SIDE	in	1x.7"	.5x1"	.7x1.3	1/2" crack	.3x3	7.6x76.2	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
C-SCAN DAMAGE	mm	2.5x17.8	12.7x25.4	17.8x33	12.7	7.6x76.2	7.6x76.2	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
2.54cm 1"																				
(in lb)	10	20	30	30	10	20	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Joules	1.13	2.26	3.39	3.39	1.13	2.26	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39
C-SCAN DAMAGE AREA (in ²)	1.95	2.73	4.87	4.87	.325	2.6	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16
COMMENTS	Very heavy splintering, some delamination & broken fibers	Very heavy splintering, some delamination & broken fibers	Very heavy splintering, some delamination & broken fibers	Very heavy splintering, some delamination & broken fibers	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy	No splintering or broken fibers, surface delamination is heavy

FIGURE A-15 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING CIBA GEIGY #1M RESIN REFERENCE PANEL

RESIN TYPE Hydantoin Epoxy

HARDENER Aromatic Amine

MODIFICATION Thermoplastic

THICKNESS 1.09 mm (0.43")

% RESIN 26.5

VOID -.45

	9.52cm (3.75") SUPPORT									
	3.17cm (125") SUPPORT	1.58cm (5/8") ROUND								
JOULES (in lb)	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND
	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.65(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)
VISUAL FRONT SIDE	OK	OK	Broken Fibers	OK	OK	OK	OK	OK		1.58cm (5/8") Dent Splintering
VISUAL BACK SIDE	in	.2x1.5"	.4x1.3"	7" Crack	.3x2.4"	1/4" dent				1x3.7"
	mm	5.1 x 3.8	10.2 x 3.3	17.8	7.6 x 6.1			OK		25.4 x 17.8
C-SCAN DAMAGE										
C-SCAN DAMAGE AREA (in ²)	1.95 (.30)	1.82 (.28)	2.86 (.44)	.78 (.12)	1.56 (.24)	2.40 (.37)	.52 (.08)	1.56 (.24)	3.96 (.61)	10.27 (1.58)
COMMENTS	Heavy splintering - slight delamination		Delamination, no broken fibers, no splinters		Very heavy splintering, heavy delamination, broken fibers					

FIGURE A-16 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING CIBA GEIGY #3 RESIN REFERENCE PANEL

RESIN TYPE Hydrantoin Epoxy

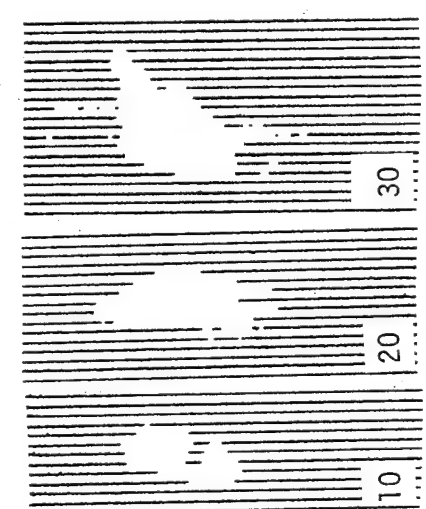
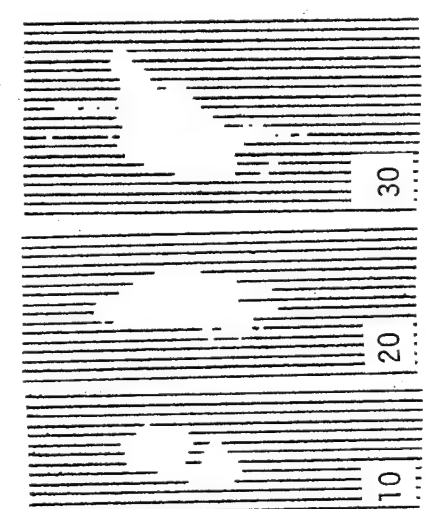
HARDENER Aromatic Amine

MODIFICATION

THICKNESS 1.07mm (.042")

% RESIN 24.6

VOID 1.3

JOULES(in lb)	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT											
	1.58cm (5/8") SUPPORT		ROUND	1.58cm (5/8") ROUND		1.58cm (5/8") FLAT									
	1.13(10)	2.26(20)		3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	OK	6.34mm (1/4") dent								OK	OK	OK		
VISUAL BACK SIDE		.2x1	.3x1.5												
	OK	5.1x25.4	7.6x38								OK	OK	OK		
C-SCAN DAMAGE															
2.54cm															
(in lbs)	10	20	30								70	80	90		
Joules	1.13	2.26	3.39								7.91	9.04	10.2		
C-SCAN ² DAMAGE AREA (in ²)	.845	1.30	2.34								.065	1.75	2.99		
	(.13)	(.20)	(.36)								(.01)	(.27)	(.46)		
COMMENTS	Splintering and delamination			No visible damage											

MODIFICATION Thermoplastic

VOID 0.9

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FIGURE A-18 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING FIBREDUX 914 RESIN REFERENCE PANEL

RESIN TYPE Multifunctional Epoxy

HARDENER Undisclosed

MODIFICATION Thermoplastic

THICKNESS 1.07mm (.042")

% RESIN 23.5

VOID 1.2

	9.52cm (3.75") SUPPORT									
	3.17cm (125") SUPPORT					1.58cm (5/8") FLAT				
	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND	1.58cm (5/8") ROUND
JOULES (IN LBS)	1.13(10)	2.26(20)	3.39(30)	3.39(30)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	3.39(30)	3.39(30)
VISUAL FRONT SIDE	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
VISUAL BACK SIDE	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
mm	2.2 X .4	2.2 X .4	3.3 X .5	3.3 X .5	3.3 X .5	2.2 X .4	2.2 X .4	3.3 X .5	3.3 X .5	3.3 X .5
C-SCAN DAMAGE	2.54cm	2.54cm	2.54cm	2.54cm	2.54cm	2.54cm	2.54cm	2.54cm	2.54cm	2.54cm
(inch lbs)	10	20	30	30	30	10	20	30	30	30
Joules	1.13	2.26	3.39	3.39	3.39	1.13	2.26	3.39	3.39	3.39
C-SCAN DAMAGE (in ²) AREA	1.17 (.18)	2.21 (.34)	2.73 (.42)	2.73 (.42)	2.73 (.42)	0 (.00)	1.23 (.19)	3.18 (.49)	3.18 (.49)	3.18 (.49)
COMMENTS										

FIGURE A-19 IMPACT DAMAGE DATA FOR (0/+45/90)_s LAMINATE USING FIBREDUX 920 RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A

THICKNESS 1.12mm (.044")

HARDENER, Aliphatic Amine

% RESIN	31.7
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MODIFICATION Thermoplastic

1.3
VOID

		9.52cm (3.75") SUPPORT									
		1.58cm (5/8") ROUND					1.58cm (5/8") FLAT				
Joules (in lb)		3.17cm (125")	1.58cm (5/8")	1.58cm (5/8")	1.58cm (5/8")	1.58cm (5/8")	1.58cm (5/8")	1.58cm (5/8")	1.58cm (5/8")	1.58cm (5/8")	1.58cm (5/8")
		1.13 (10)	2.26 (20)	3.39 (30)	3.39 (30)	3.39 (30)	3.39 (30)	3.39 (30)	3.39 (30)	3.39 (30)	3.39 (30)
VISUAL FRONT SIDE		OK	OK	6.35mm (1/4") dent	OK	OK	OK	3.17mm (1/8") dent	OK	OK	OK
VISUAL BACK SIDE	in	OK	.4x.3"	.5x.5"	OK	OK	OK	.5x.3"	OK	OK	OK
C-SCAN DAMAGE	mm	OK	10.2x7.5	12.7x12.7	OK	OK	OK	12.7x7.5	OK	OK	OK
2.54cm 1"											
(inch lbs)		10	20	30	10	20	30	10	20	30	70
Joules		1.13	2.26	3.39	1.13	2.26	3.39	7.91	9.04		
C-SCAN DAMAGE AREA (in ²)		.325 (.05)	1.10 (.17)	1.43 (.22)	.065 (.01)	.65 (.10)	1.56 (.24)		5.39 (.83)	6.63 (1.02)	
COMMENTS		Broken fibers - slight splintering				Broken fibers & slight splintering				Broken fibers, long 90° cracks	

FIGURE A-20 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING FIBREDUX 920 (LOW RESIN) RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A

THICKNESS 1.09 mm (.043")

HARDENER Aliphatic Amine

% RESIN 29.2

MODIFICATION Thermoplastic

VOID 0.5

		9.52cm (3.75") SUPPORT									
		3.17cm (125") SUPPORT					1.58cm (5/8") FLAT				
		1.58cm (5/8")	2.26(20)	3.39(30)	1.58cm (5/8")	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)
JOULES (IN LB)		1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)
VISUAL FRONT SIDE		OK	3.17mm (1/8") dent	6.35mm (1/4") dent	OK	OK	6.35mm (1/4") dent broken fibers			OK	1.58cm (5/8") dent
VISUAL BACK SIDE		in	2x.1"	.4x.3"	.5x.5"	.2x.4"	.4x.4"			1.5x1.0	1.5x1.7
		mm	5.1x2.5	10.2x7.6	12.7x12.7	5.1x10.2	10.2x10.2			38x25.4	38x43.2
C-SCAN DAMAGE											
2.54cm 1" 0											
(in lbs)											
Joules		1.13	2.26	3.39	1.13	2.26	3.39	6.78	7.91	9.04	
C-SCAN DAMAGE AREA (in ²)		.195	1.43	2.27	0	.45	1.49	0	4.87	4.81	
		(.03)	(.22)	(.35)	(.00)	(.07)	(.23)	(.00)	(.75)	(.74)	
COMMENTS		Broken fibers and delamination					Broken fibers, delamination at 3.39 joules (30 in 1b)				
		Broken fibers and heavy delamination									

FIGURE A-21 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING U.S. POLY #1 RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A

HARDENER Specialty Aromatic Amine

MODIFICATION Elastomers

THICKNESS 1.02mm (.040")

% RESIN 24.6

VOID 1.3

9.52cm (3.75") SUPPORT														
3.17cm (125") SUPPORT			1.58cm (5/8") FLAT											
Joules(in lb)	1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	dent broken fibers	OK	OK	3.17mm (1/8") dent			OK		dent broken fibers			
VISUAL BACK SIDE	in .2x.1	.3x.2	.4x.7		.2x.1	.4x.6					1.5x.5			
	5.1x2.5	7.6x5.1	10.2x17.8	OK	5.1x2.5	10.2x15.2			OK		38x12.7			
C-SCAN DAMAGE														
(in lbs)	10	20	30	10	20	30			50	60	80			
Joules	1.13	2.26	3.39	1.13	2.26	3.39			5.56	6.78	9.04			
C-SCAN DAMAGE AREA(in ²)	.58 (.09)	.84 (.13)	1.75 (.27)	.065 (.01)	.52 (.08)	1.49 (.23)			0 (.00)	.19 (.03)	6.95 (1.07)			
COMMENTS	Broken fibers & delamination			Broken fibers and delamination			Broken fibers and delamination							

FIGURE A-22 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING U.S. POLY #2 RESIN REFERENCE PANEL

RESIN TYPE	Bis Phenol A	THICKNESS	1.02mm (.040")
HARDENER	Specialty Aromatic Amine	% RESIN	24.8
MODIFICATION	Elastomers	VOID	0.9

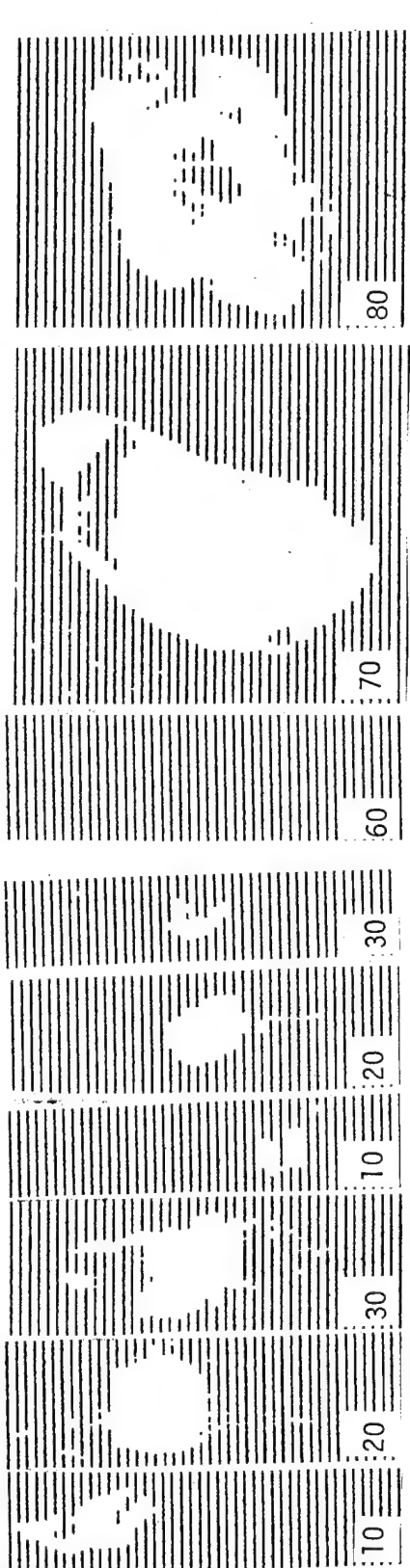
		9.52cm (3.75") SUPPORT													
		3.17cm (125") SUPPORT			1.58cm (5/8") ROUND			1.58cm (5/8") FLAT							
Joules(in lb)		1.13(10)	2.26(20)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)	13.60(120)
VISUAL FRONT SIDE		OK	OK	3.17mm (1/8") dent broken fibers	OK	OK	OK			OK	OK	1.58cm (5/8") hole broken fibers 90° crack			
VISUAL BACK SIDE	in	OK	.2x1"	.4x1.2"	OK						.1x.1	.9x1.1			
	mm		5.1 x 25.4	10.2 x 30.5	OK	OK	OK	OK			2.5 x 2.5	22.8 x 22.8			
C-SCAN DAMAGE															
2.54cm	1"														
	0														
(in lbs)		10	20	30	10	20	30	60	70	80					
Joules		1.13	2.26	3.39	1.13	2.26	3.39	6.78	7.91	9.04					
C-SCAN DAMAGE AREA(in ²)		1.10 (.17)	1.82 (.28)	1.69 (.26)	.52 (.08)	1.23 (.19)	.455 (.07)				9.68 (1.49)	7.67 (1.18)			
COMMENTS		Delamination, some splintering and broken fibers			Undamaged			Broken fibers, no splintering, delamination at 9.04 joules (80 in lbs)							

FIGURE A-23 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING HEXCEL #1 RESIN REFERENCE PANEL

RESIN TYPE Bis Phenol A
 HARDENER Dicyandiamide
 MODIFICATION Elastomer

THICKNESS 1.09mm (.043")
 % RESIN 28.8
 VOID -1.0

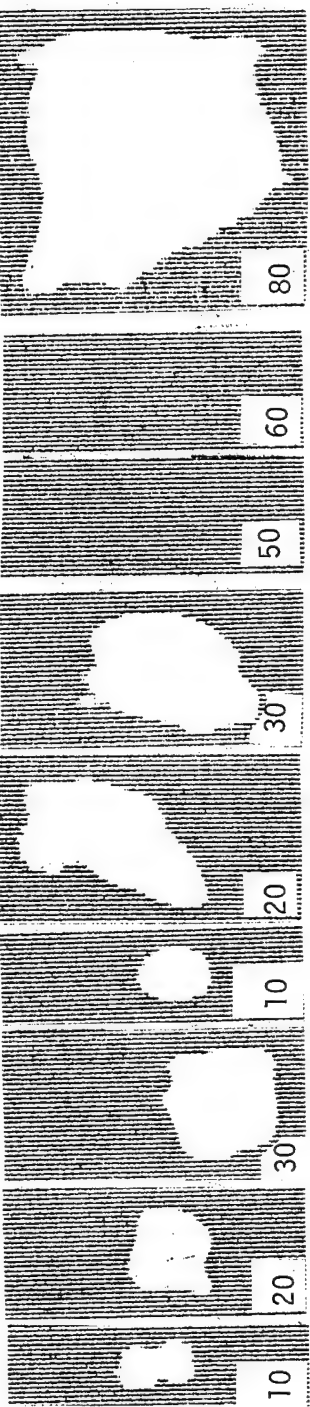
	3.17cm (125") SUPPORT			9.52cm (3.75") SUPPORT									
	1.58cm (5/8")	ROUND	3.39 (30)	1.58cm (5/8")	ROUND	1.58cm (5/8")	FLAT	1.58cm (5/8")	FLAT	1.58cm (5/8")	FLAT	1.58cm (5/8")	FLAT
Joules (in lb)	1.13 (10)	2.26 (20)	3.39 (30)	1.13 (10)	2.26 (20)	3.39 (30)	4.52 (40)	5.56 (50)	6.78 (60)	7.91 (70)	9.04 (80)	10.20 (90)	11.30 (100)
VISUAL FRONT SIDE	OK	3.17mm (1/8") dent	6.35mm (1/4") dent	OK	OK	6.35mm (1/4") dent		OK	OK		1.58cm (5/8") dent broken fibers		
VISUAL BACK SIDE	OK	.3x.2"	.3x.3"	OK	.4x.4"	.4x1.0"		OK	OK		1.1x.7"		
C-SCAN DAMAGE													
	10	20	30	10	20	30	30	50	60	80			
Joules	1.13	2.26	3.39	1.13	2.26	3.39	5.56	6.78	9.04				
C-SCAN DAMAGE AREA (in ²)	.52 (.08)	1.10 (.17)	2.01 (.31)	.455 (.07)	2.86 (.44)	2.86 (.44)					9.94 (1.53)		
COMMENTS	Broken fibers - slight splintering but no spread, slight delamination			Broken fibers and delamination - slight splintering			Broken fibers, crack propagated 0° no splintering, no delamination						

FIGURE A-24 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING HEXCEL #2 RESIN REFERENCE PANEL

RESIN TYPE	Bis-Phenol A	THICKNESS	1.14mm (.045")
HARDENER	Dicyandiamide	% RESIN	28.9
MODIFICATION	Elastomer	VOID	1.5

	9.52cm (3.75") SUPPORT									
	3.17cm(125") SUPPORT					1.58cm (5/8") ROUND				
	1.58cm(5/8")	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)
Joules(in lb)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)	6.78(60)	7.91(70)	9.04(80)	10.20(90)	11.30(100)
VISUAL FRONT SIDE			OK						1.58cm (5/8") hole cracks prop. 0° & 90°	13.60(120)
VISUAL BACK SIDE			1" crack 0°						1x1.5	
mm			25.4							
C-SCAN DAMAGE										
2.54cm 1" 0										
(in lb)										
Joules	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	10.20	
C-SCAN DAMAGE AREA(in ²)		5.2 (.80)							9.68 (1.49)	
COMMENTS	Blister	Slight splinters, some broken fibers				Heavy delamination, broken fibers, some splintering				

FIGURE A-25 IMPACT DAMAGE DATA FOR (0/+45/90)s LAMINATE USING FIBERITE HY-E 976 RESIN REFERENCE PANEL

THICKNESS	1.17 (0.46)
% RESIN	29.6
VOID	1.12
MODIFICATION	None

		9.52cm (3.75") SUPPORT									
		3.17cm (125") SUPPORT					1.58cm (5/8") FLAT				
		1.58cm (5/8") ROUND					1.58cm (5/8") ROUND				
Joules (in lb)		1.13(10)	2.26(20)	3.39(30)	3.39(30)	3.39(30)	1.13(10)	2.26(20)	3.39(30)	4.52(40)	5.56(50)
VISUAL FRONT SIDE		OK	3.17mm (1/8") dent	6.35mm (1/4") dent	3.39(30)	3.39(30)	OK	OK	OK	OK	OK
VISUAL BACK SIDE		in	.2x1.2	.4x1.2	.2x.8	.2x2					
		mm	5.1x30.5	10.2x30.5	5.08x20.3	5.08x50.8	OK	OK	OK	OK	OK
C-SCAN DAMAGE											
2.54cm [1"] 0											
(in lb)		10	20	30	10	20	30	50	60	70	80
Joules		1.13	2.26	3.39	1.13	2.26	3.39	5.56	6.78	7.91	9.04
											10.20
C-SCAN cm ² DAMAGE AREA(in ²)		2.34 (.36)	3.31 (.51)	5.13 (.79)	.455 (.07)	1.17 (.18)	2.40 (.37)	.975 (.15)	2.73 (.42)	5.59 (.86)	3.64 (.56)
COMMENTS		Delamination at 3.39 joules (30 in lb) heavy splintering					Broken fibers, 10.20 joules (90 in lb) heavy damage with some splintering				

APPENDIX 2

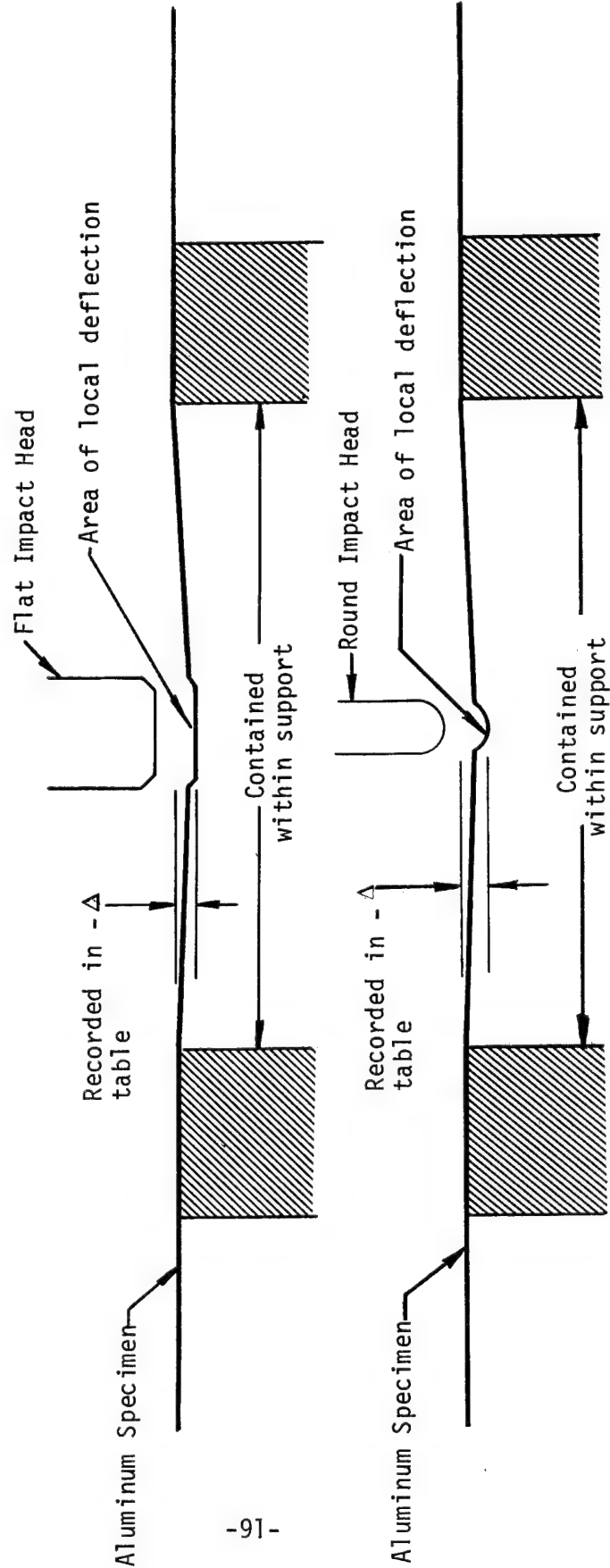
ALUMINUM IMPACT DATA (GARDNER)

Photographs B-1 through B-12 show the damage to .98 mm and .61 mm thick aluminum alloy 2024-T3 impacted at the same levels as the graphite/epoxy laminates. The .98 mm sheet is approximately the same thickness as the GR/EP panels and the .61 mm sheet is approximately equal weight for a given surface area as the composite panels.

There was no fracturing, however the aluminum yielded significantly in the direction of impact; the area of damage was equal to the area within the back support. As would be expected the maximum deformation took place at the point of impact, this deflection is recorded in Table B-1.

TABLE B-1 DEFORMATION AFTER IMPACT

	3.17cm (1.25") SUPPORT 5/8" ROUND			9.52cm (3.75") SUPPORT ROUND				1.58cm (5/8") SUPPORT FLAT			
	1.13 (10)	2.26 (20)	3.39 (30)	1.13 (10)	2.26 (20)	3.39 (30)	4.52 (40)	6.78 (60)	9.04 (80)	11.3 (100)	
Joules (in lb)	0.66 (.026)	1.07 (.042)	1.57 (.062)	0.51 (.020)	0.91 (.036)	1.40 (.055)	1.47 (0.58)	2.13 (0.84)	2.69 (.106)	2.79 (.110)	
Δ for 2024-T3 .98mm (.040")	1.22 (.048)	1.65 (0.65)	1.85 (0.73)	0.99 (.039)	1.35 (.053)	1.55 (.061)	1.73 (.068)	2.51 (0.99)	2.82 (.111)	3.86 (.152)	



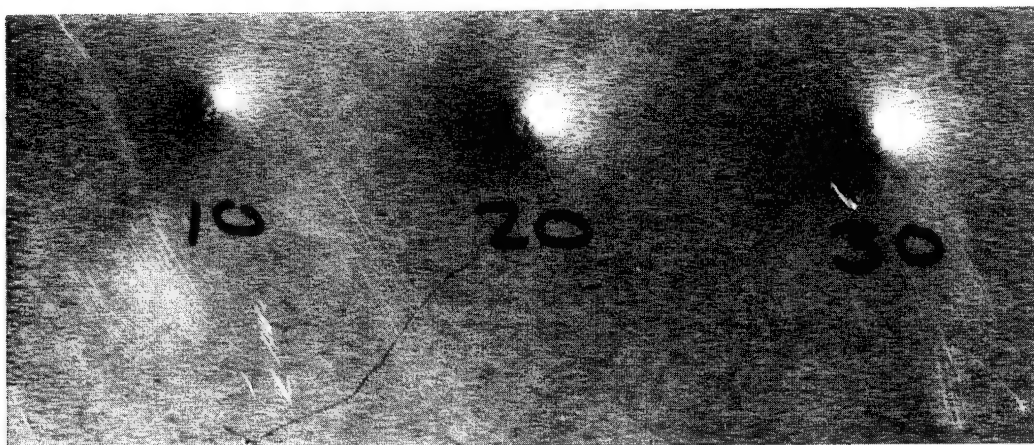


FIGURE B-1 2024-T3 .98 mm (.040") 14.9 mm (5/8") ROUND, 31.7 mm (1.25")
SUPPORT 1.13 (10), 2.25 (20), 3.39 JOULES (30 INCH POUNDS)

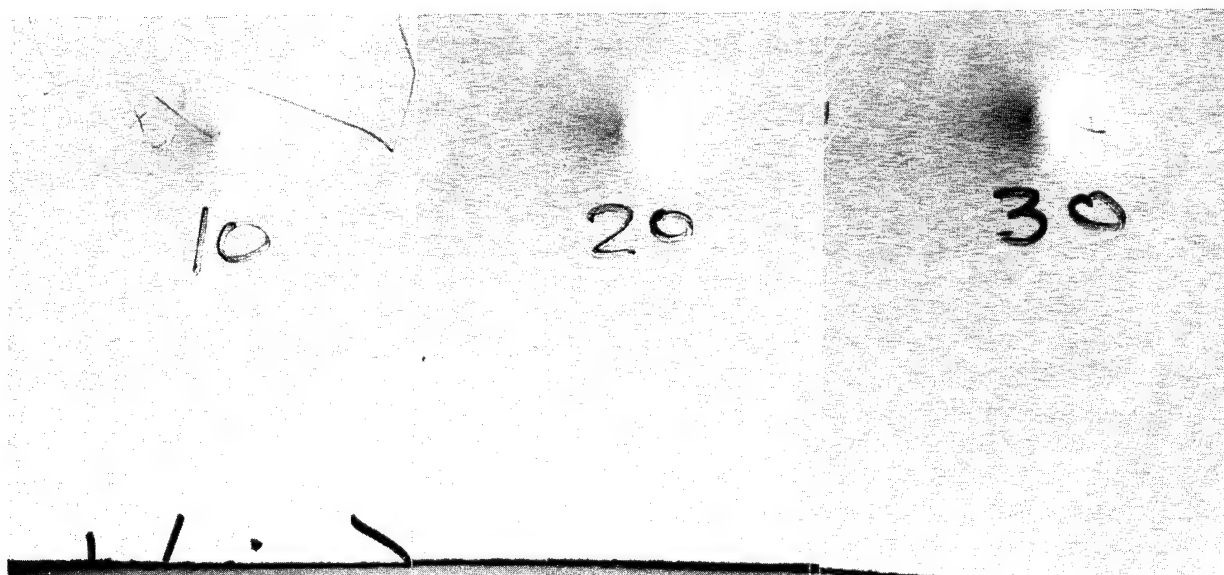


FIGURE B-2 2024-T3 .98 mm (.040") 15.9 mm (5/8") ROUND, 95.3 mm (3.75")
SUPPORT 1.13 (10), 2.26 (20), 3.39 JOULES (30 INCH POUNDS)

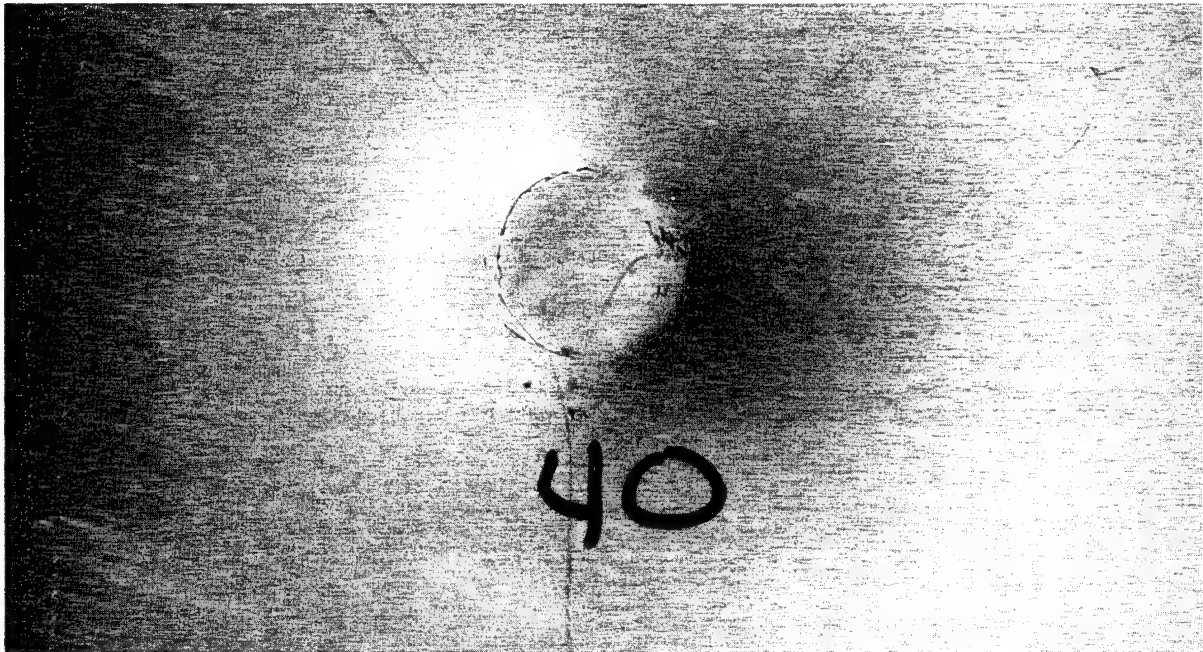


FIGURE B-3 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT, 95.3 mm (3.75") SUPPORT
4.52 JOULES (40 INCH POUNDS)

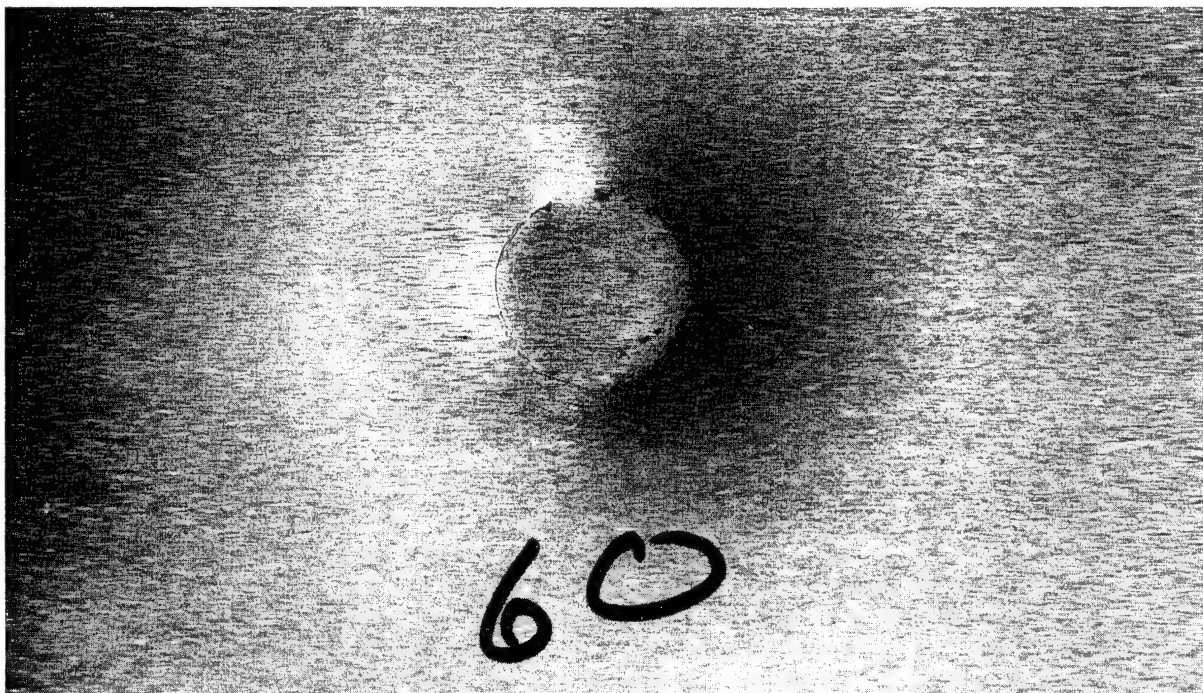


FIGURE B-4 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT 95.3 mm (3.75") SUPPORT
6.78 JOULES (60 INCH POUNDS)

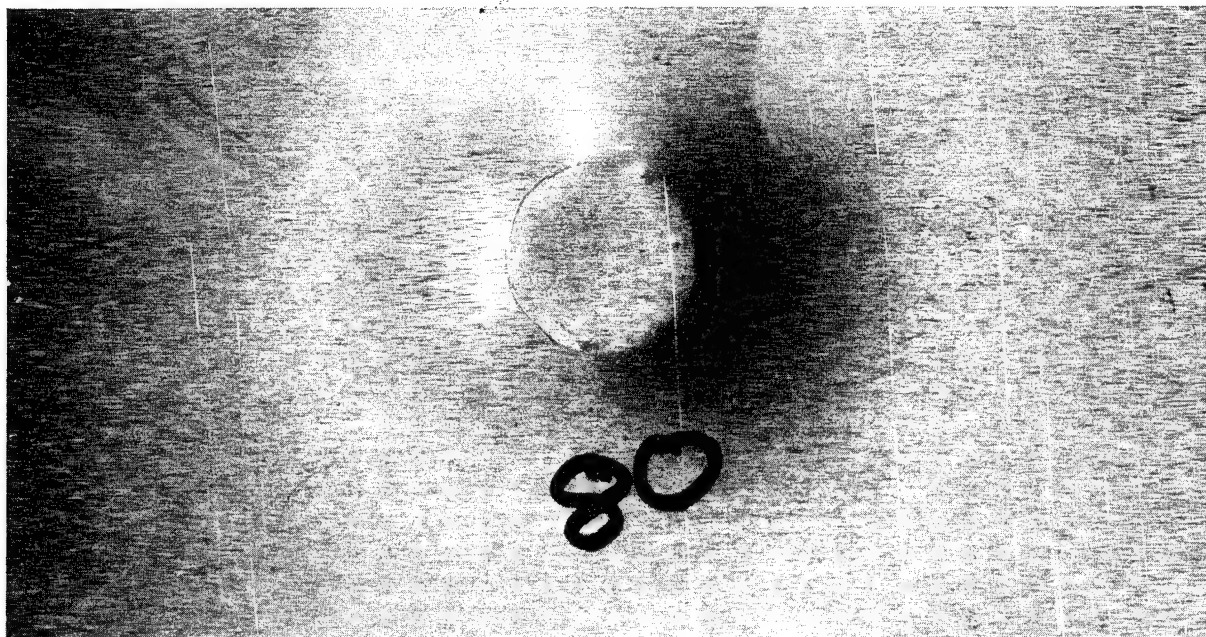


FIGURE B-5 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT 95.3 mm (3.75")
SUPPORT 6.78 JOULES (60 INCH POUNDS)

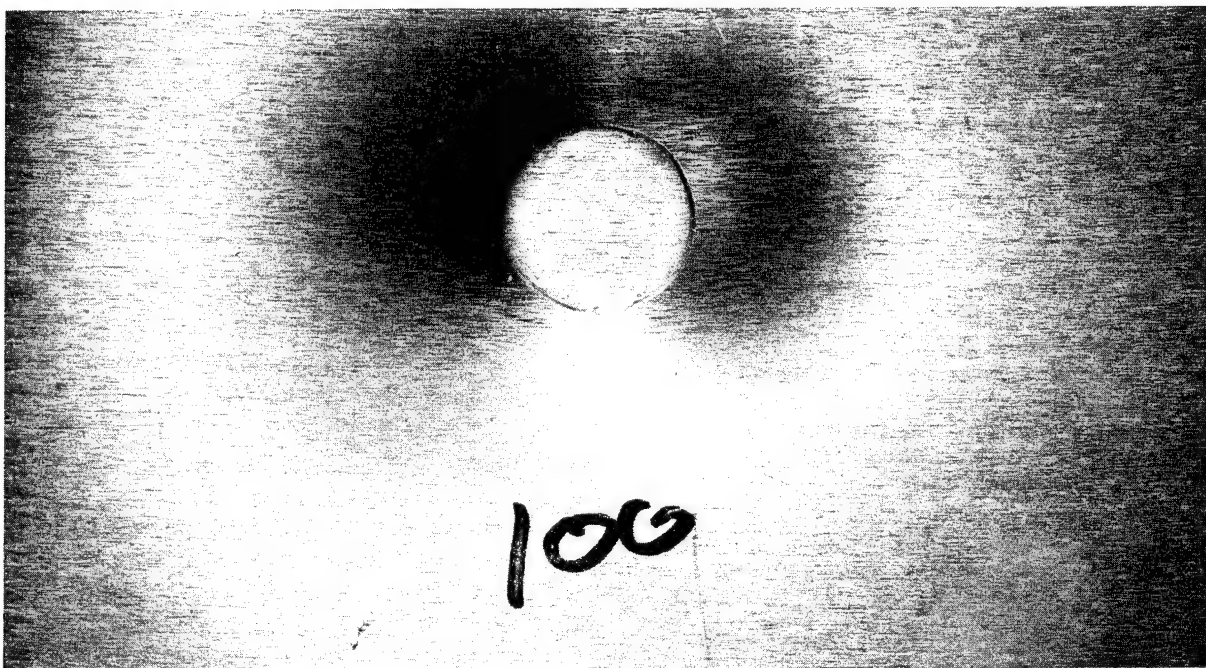


FIGURE B-6 2024-T3 .98 mm (.040") 15.9 mm (5/8") FLAT 95.3 mm (3.75")
SUPPORT 11.3 JOULES (100 INCH POUNDS)

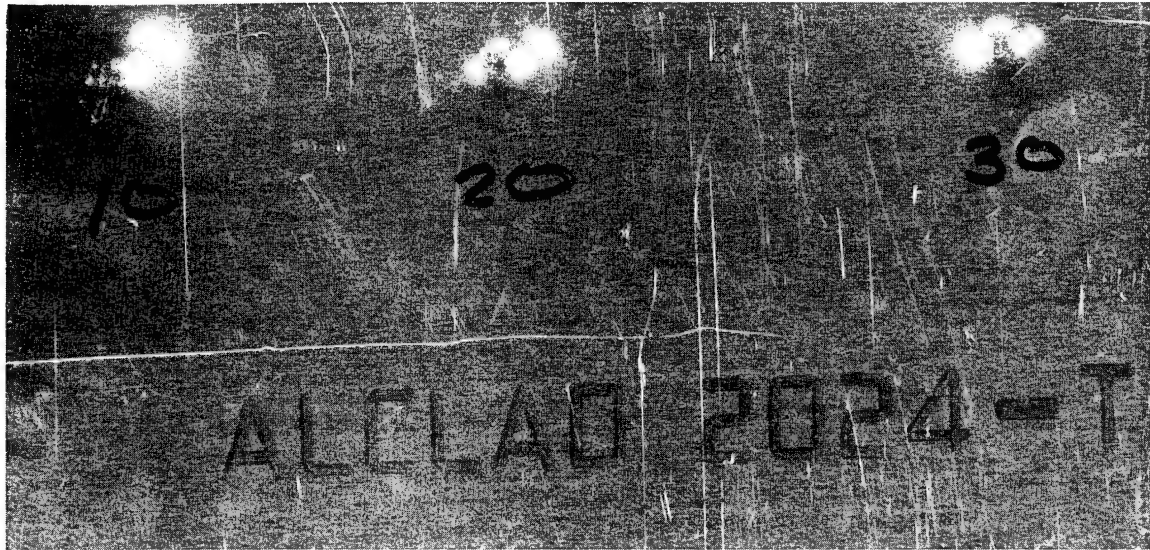


FIGURE B-7 2024-T3 .61 mm (0.25") 15.9 mm (5/8") ROUND, 31.7 mm (1.25")
SUPPORT 1.13 (10), 2.26 (20), 3.39 JOULES (30 INCH POUNDS)

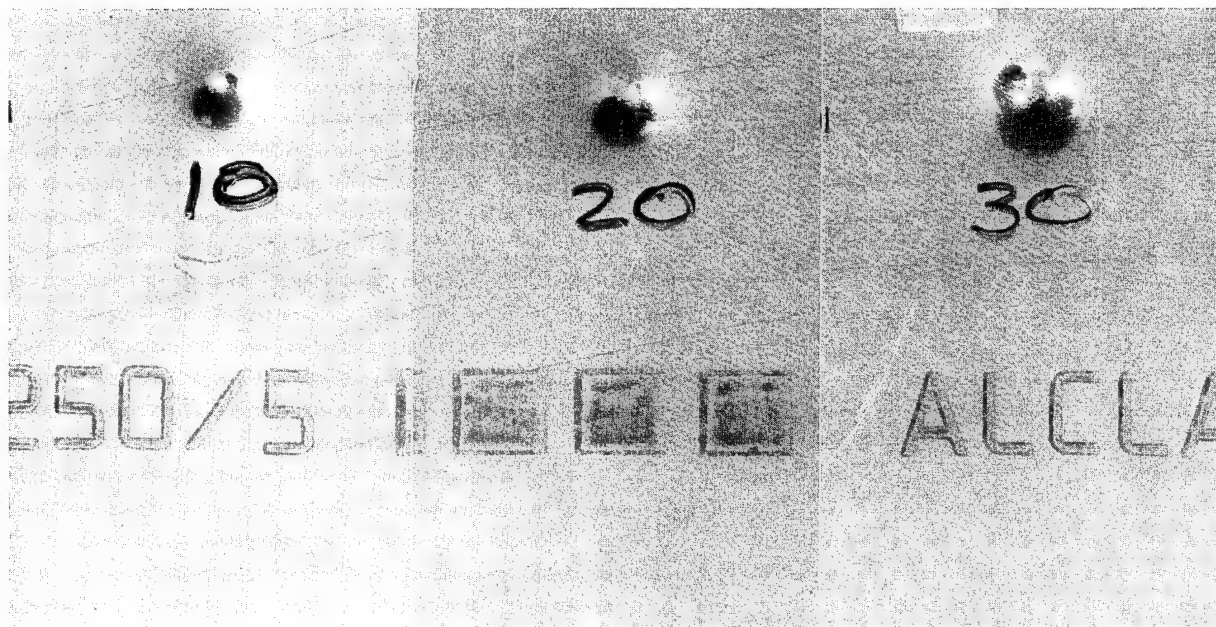


FIGURE B-8 2024-T3 .61 mm (.025") 14.9 mm (5/8") ROUND, 95.3 mm (3.75")
SUPPORT 1.13 (10), 2.25 (20), 3.39 JOULES (30 INCH POUNDS)

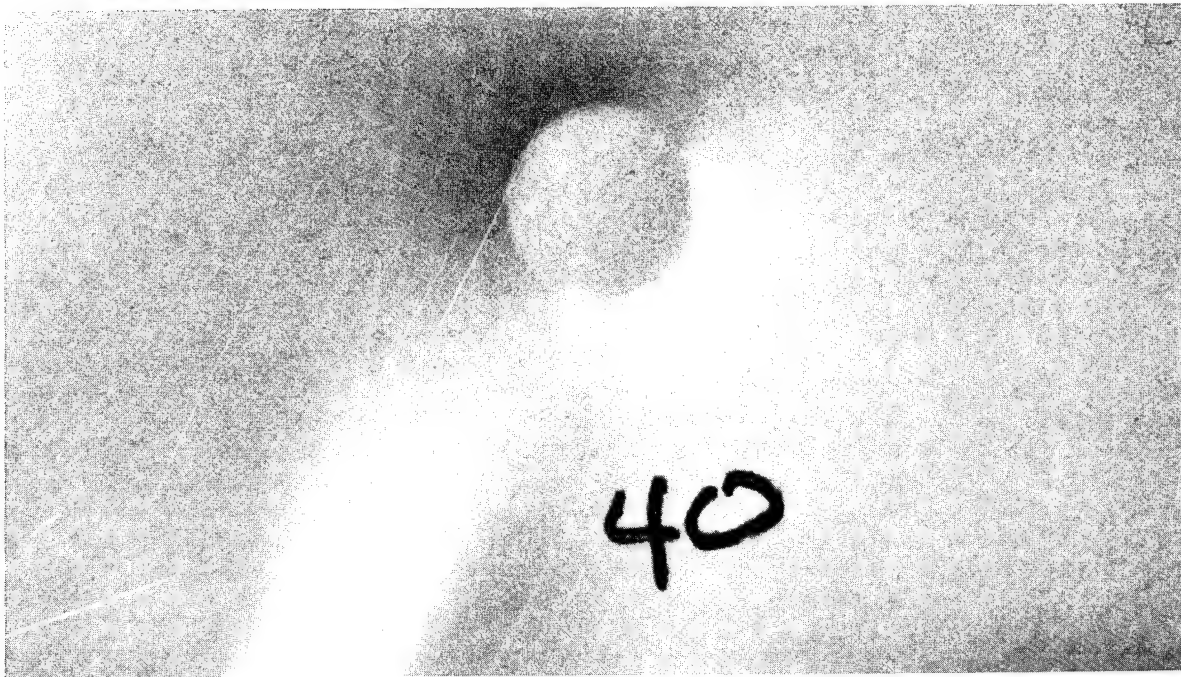


FIGURE B-9 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT, 95.3 mm (3.75")
SUPPORT 4.52 JOULES (40 INCH POUNDS)

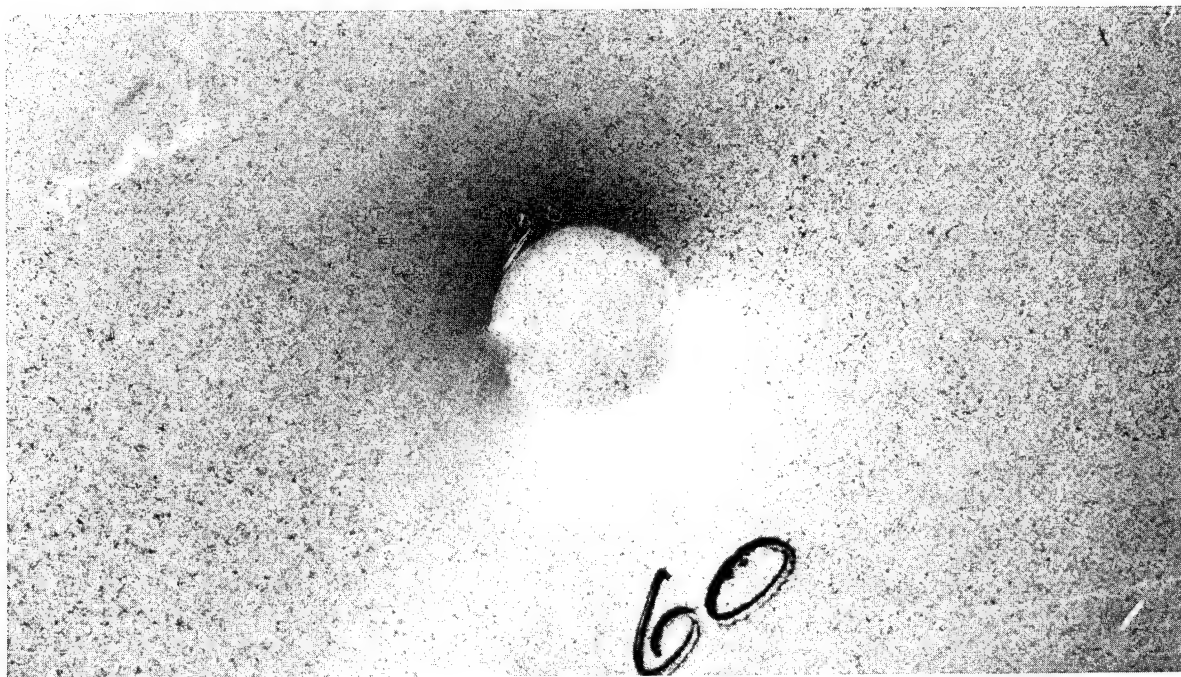


FIGURE B-10 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT 95.3 mm (3.75")
SUPPORT 6.78 JOULES (60 INCH POUNDS)

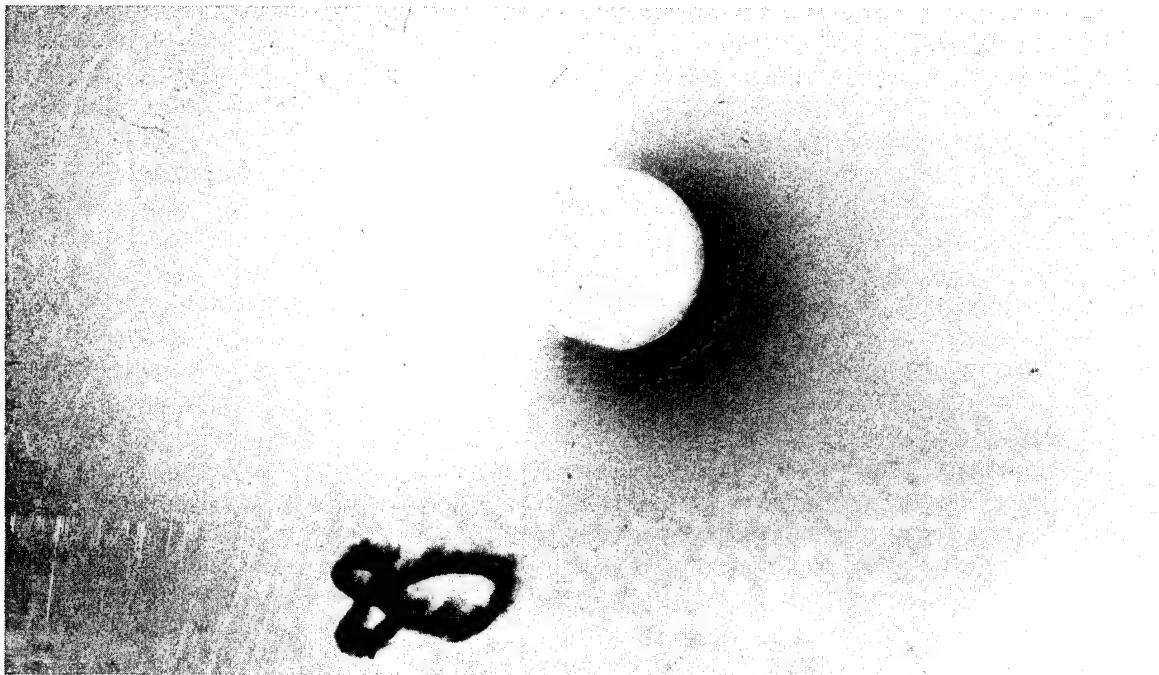


FIGURE B-11 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT 95.3 mm (3.75")
SUPPORT 9.04 JOULES (80 INCH POUNDS)

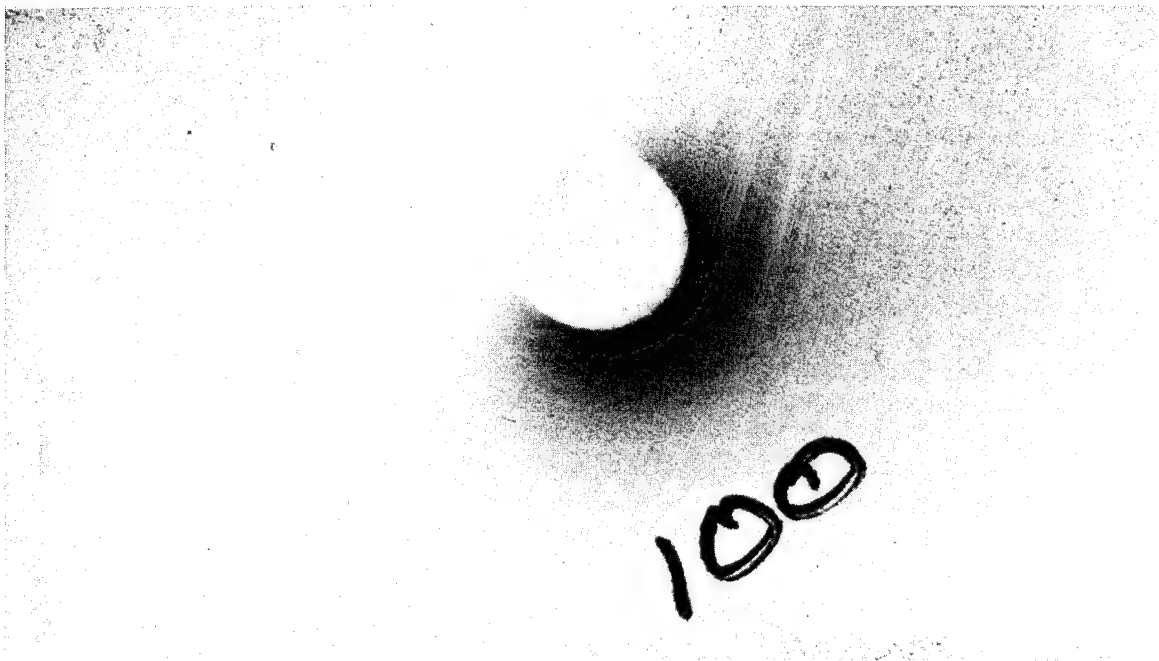


FIGURE B-12 2024-T3 .61 mm (.025") 15.9 mm (5/8") FLAT 95.3 mm (3.75")
SUPPORT 11.3 JOULES (100 INCH POUNDS)

APPENDIX 3

RHEOMETRIC CONSTANT SPEED IMPACT DATA

The Rheometric Constant Speed Penetrating Impact machine load deflection curves, data reduction for slope of curve and impact energy absorbed and X-ray of the damaged areas are recorded for ten materials in Appendix 3. Diiodobutane (DIB) was used to aid X-ray.

- ° Narmco 5208
- ° American Cyanamide BP-907
- ° Ciba Geigy #4
- ° Ciba Geigy #1M
- ° Narmco X1114
- ° Ciba Geigy Fiberdux 920
- ° American Cyanamide 982
- ° Narmco X-107
- ° American Cyanamide 919
- ° U. S. Polymeric #2

FIGURE C-1 - RHEOMETRIC AND X-RAY DATA FOR NARMCO 5208/T300 LAMINATE

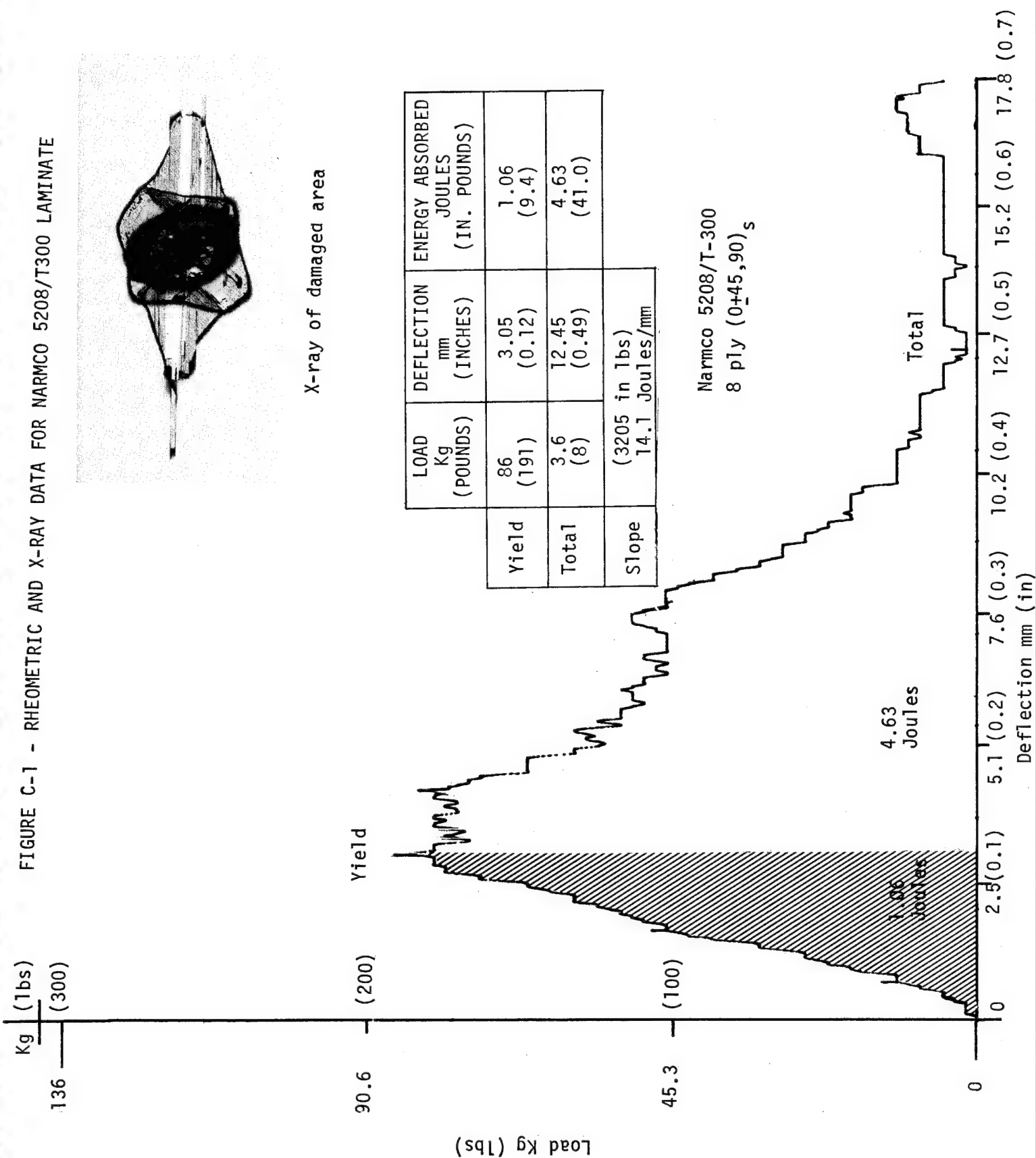


FIGURE C-2 - RHEOMETRIC AND X-RAY DATA FOR AMERICAN CYANAMID BP-907 LAMINATE

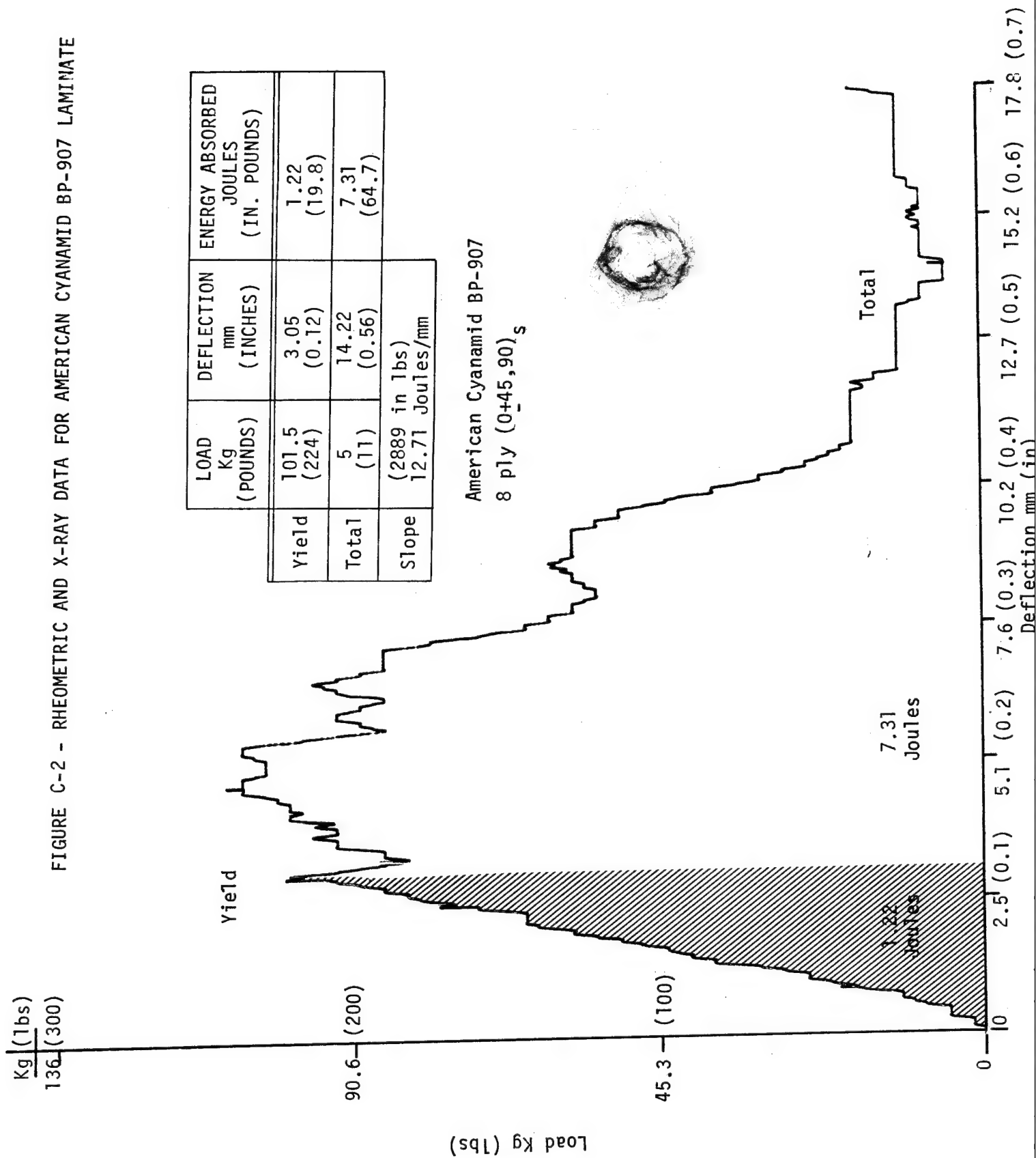


FIGURE C-3 - RHEOMETRIC AND X-RAY DATA FOR CIBA GEIGY #4

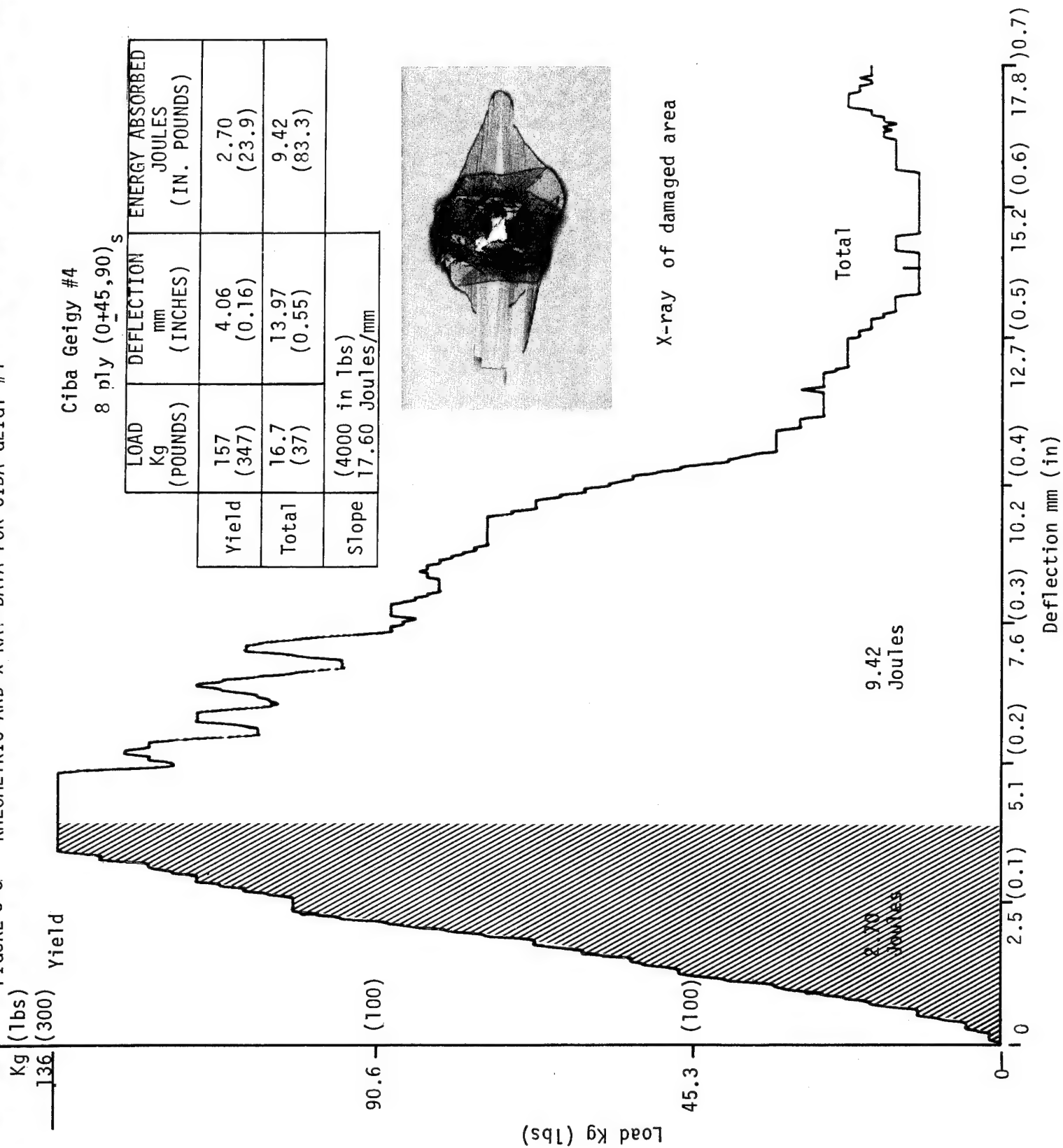


FIGURE C-4 - RHEOMETRIC AND X-RAY DATA FOR CIBA GEIGY #1M LAMINATE

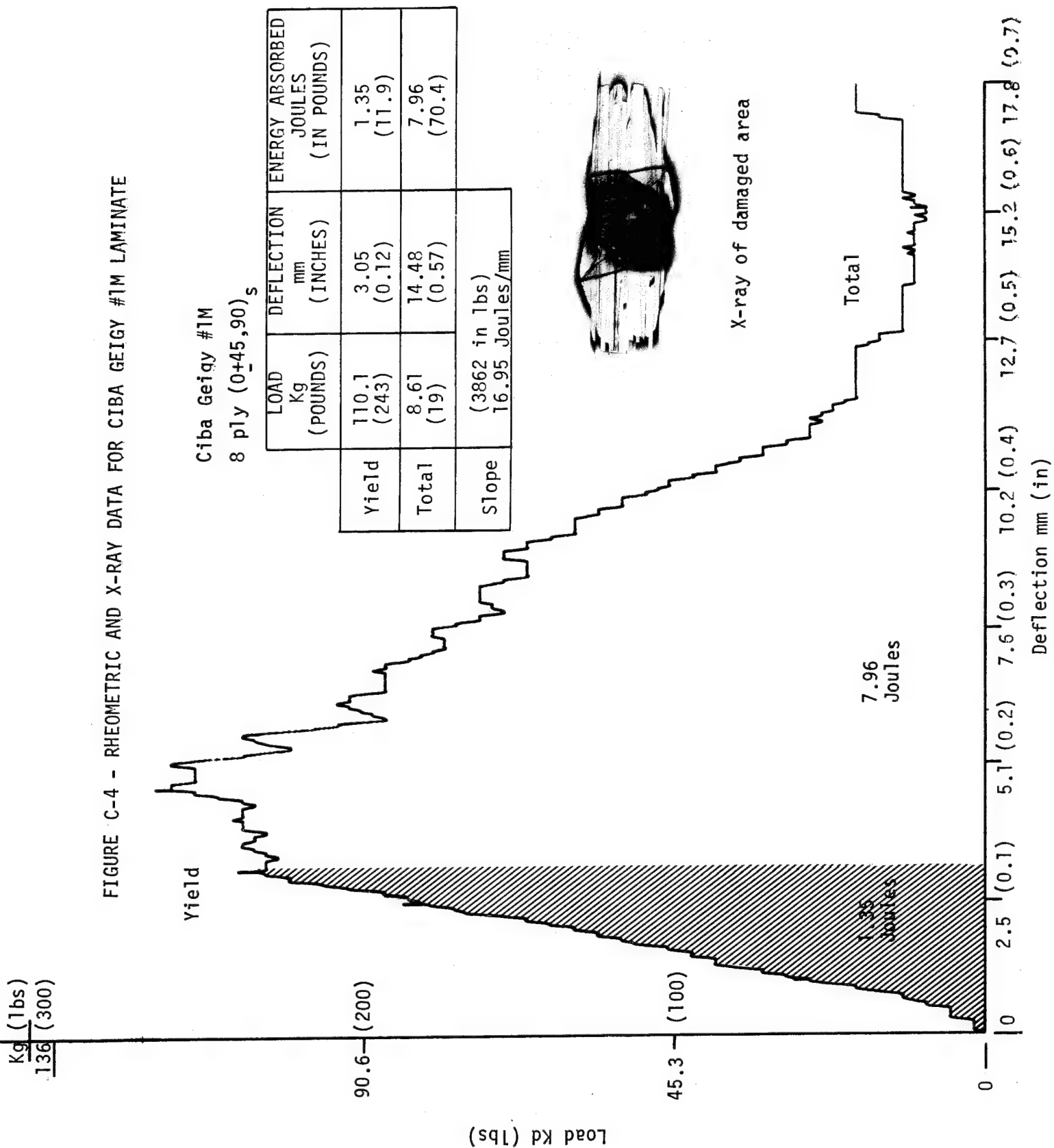


FIGURE C-5 - RHEOMETRIC AND X-RAY DATA FOR NARMCO X1114 LAMINATE

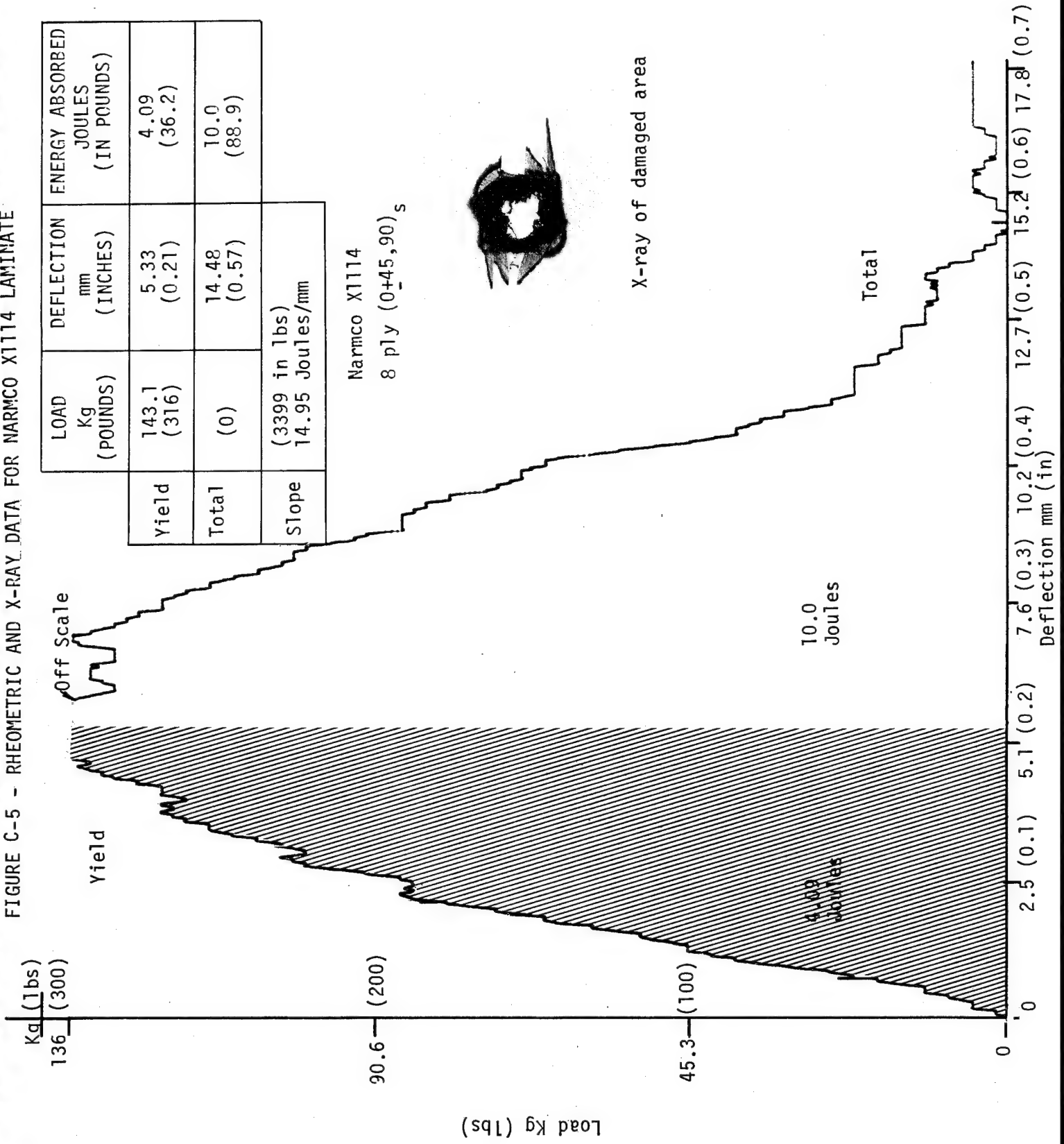


FIGURE C-6 - RHEOMETRIC AND X-RAY DATA FOR FIBERDUX 920 LAMINATE

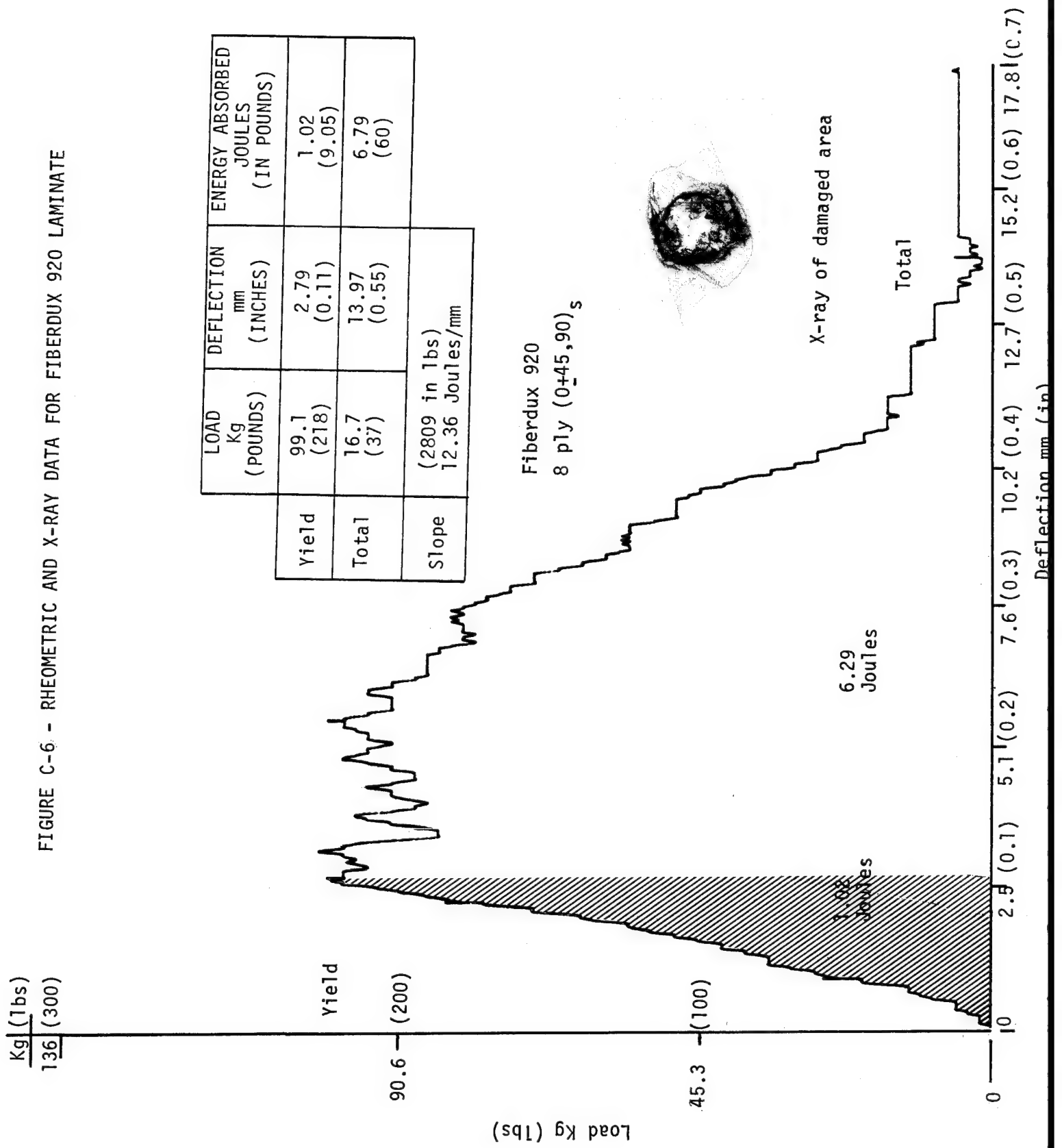


FIGURE C-7 - RHENOMETRIC AND X-RAY DATA FOR AMERICAN CYANAMID BP-982 LAMINATE

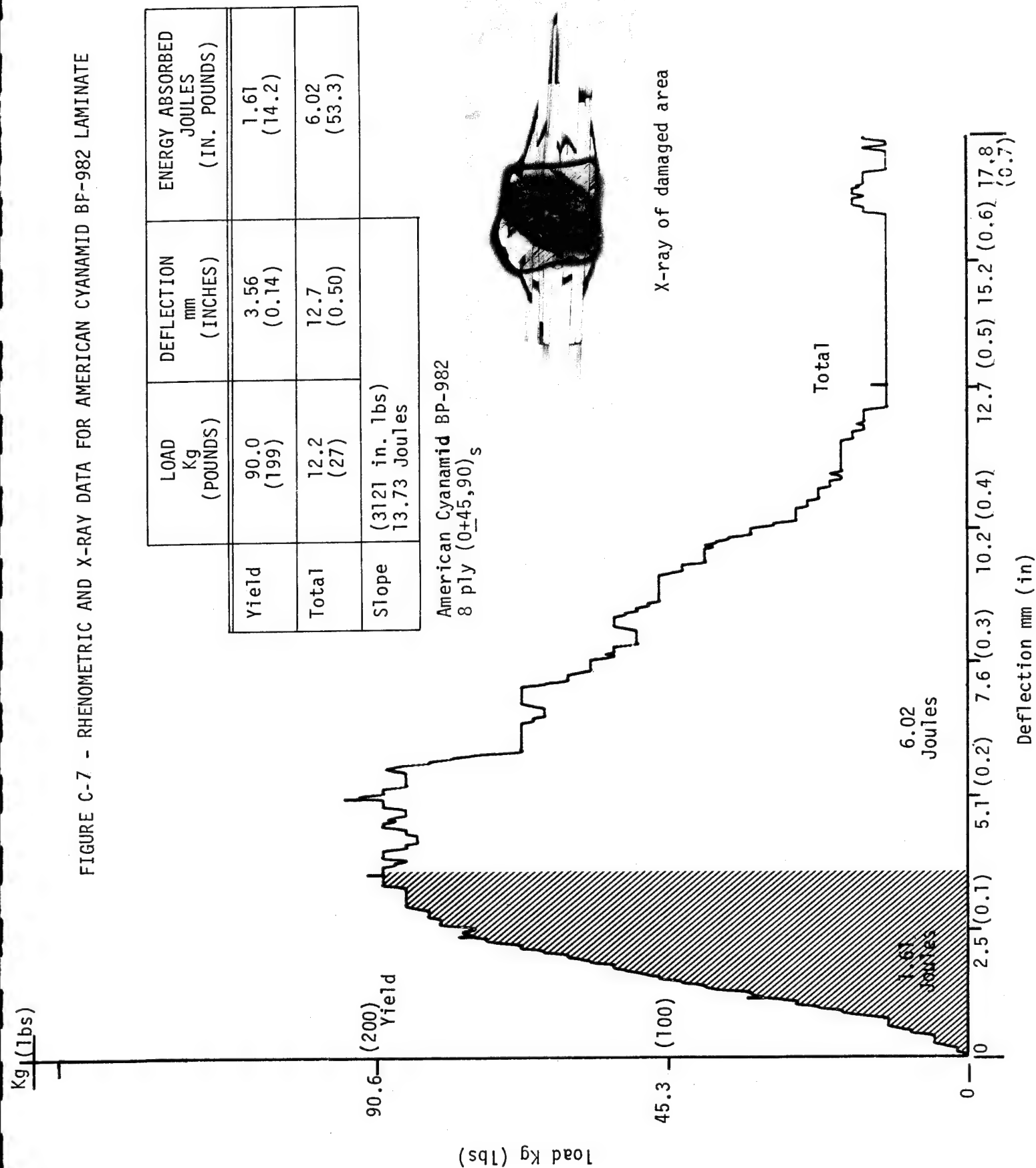
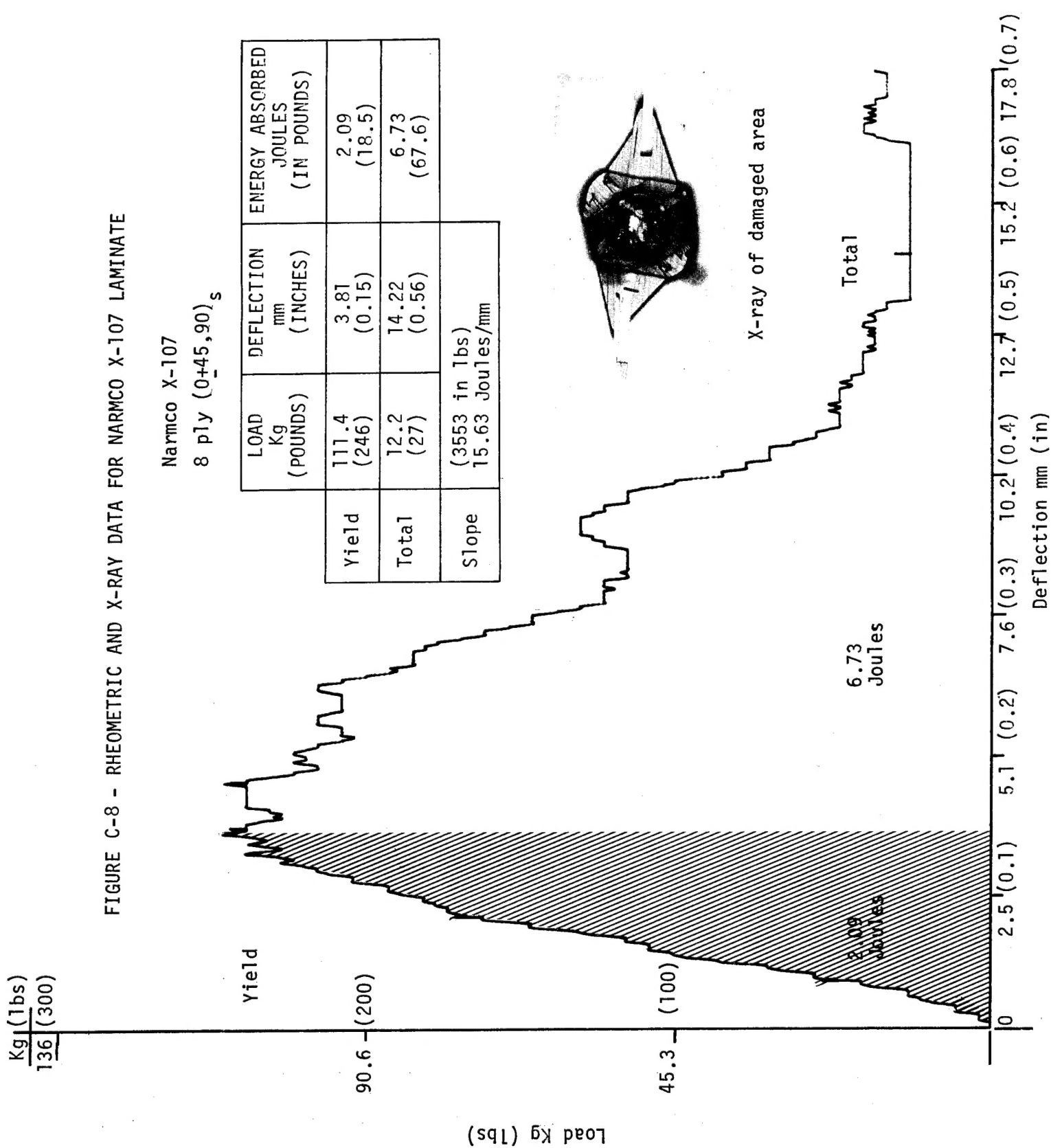


FIGURE C-8 - RHEOMETRIC AND X-RAY DATA FOR NARMCO X-107 LAMINATE

Narmco X-107

8 ply (0+45,90)_s

	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	111.4 (246)	3.81 (0.15)	2.09 (18.5)
Total	12.2 (27)	14.22 (0.56)	6.73 (67.6)
Slope	(3553 in lbs) 15.63 Joules/mm		



Kg (lbs)
136 (300)

FIGURE C-9 - RHEOMETRIC AND X-RAY DATA FOR AMERICAN CYANAMID 919 LAMINATE

	LOAD Kg (POUNDS)	DEFLECTION mm (INCHES)	ENERGY ABSORBED JOULES (IN POUNDS)
Yield	112.3 (248)	3.30 (0.13)	1.48 (13.1)
Total	1.32 (3)	13.21 (0.52)	6.39 (56.6)
Slope	(3131 in lbs) 13.78 Joules/mm		

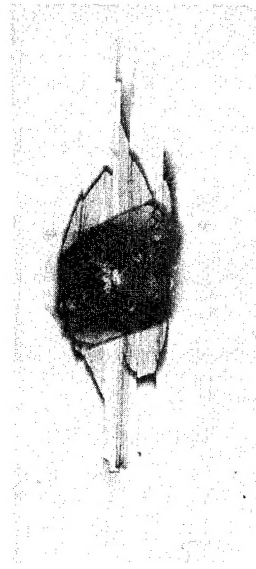
American Cyanamid 919
8 ply (0+45,90)_s

Load Kg (lbs)

Yield

90.6 (200)

45.3 (100)



X-ray of damaged area

6.39
Joules

1.48
Joules

Total

0 10

2.51 (0.1)

5.11 (0.2)

7.61 (0.3)

10.21 (0.4)

12.71 (0.5)

15.21 (0.6)

17.81 (0.7)

Deflection mm (in)

FIGURE C-10 RHEOMETRIC AND X-RAY DATA FOR U.S. POLYMERIC #2 LAMINATE

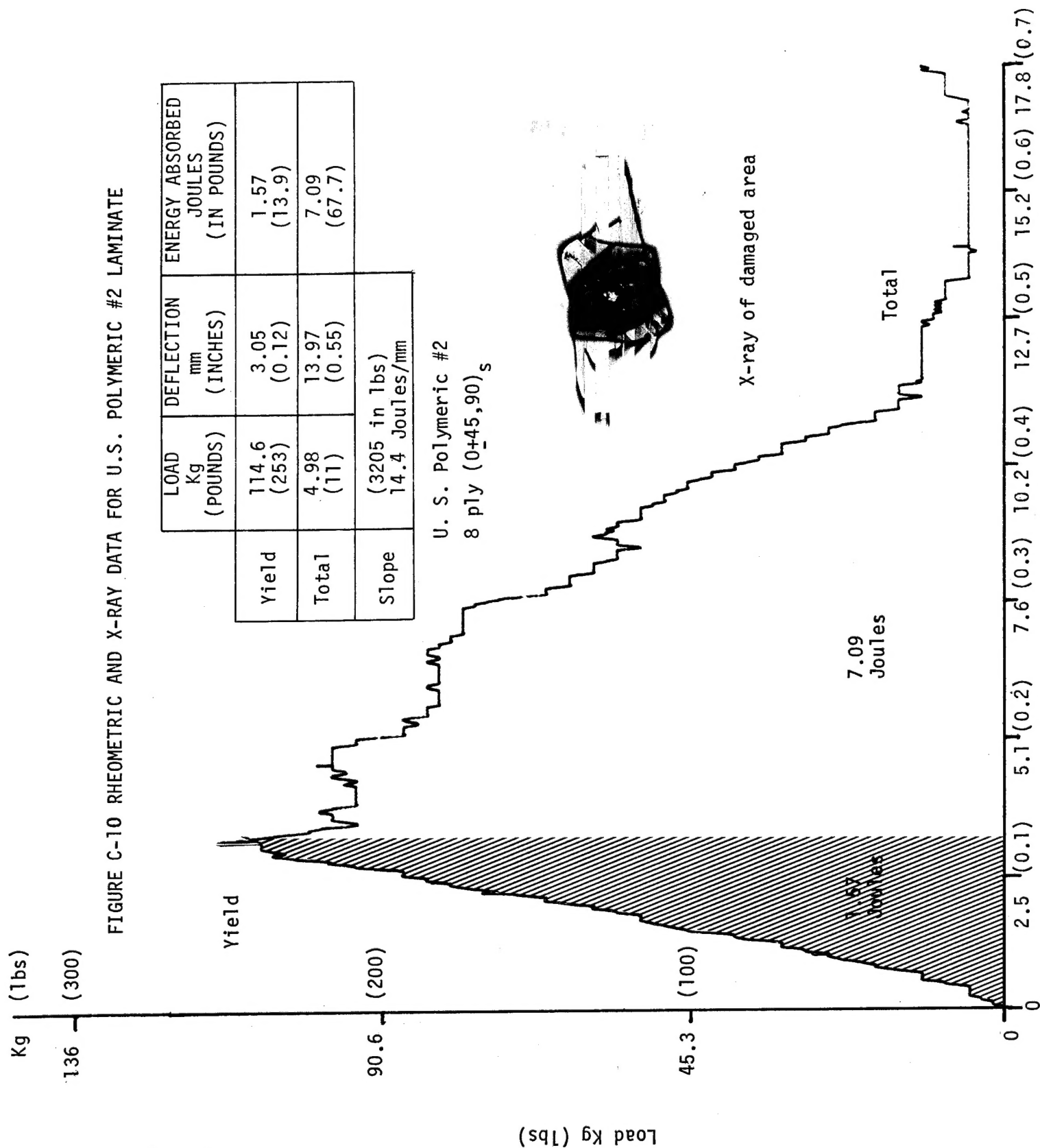


FIGURE C-11 SUMMARY RHEOMETRIC IMPACT

